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SUMMARY REPORT: PILOT PLANT STUDIES ON DEWATERING PRIMARY DIGESTED SLUDGE

John D. Parkhurst, et al

Los Angeles County Sanitation District
Los Angeles, California

August 1973

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SUMMARY REPORT: PILOT PLANT STUDIES ON DEWATERING PRIMARY DIGESTED SLUDGE

Parkhurst, J.D., Rodrigue, R.F., Miele, R.P., Hayashi, S.T.

County Sanitation Districts of
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2020 Beverly Boulevard
Los Angeles, California 90057

R801658 - 1B2043

Environmental Protection Agency report number,
EPA-670/2-73-043, August 1973.

A 14-month pilot and plant scale sludge dewatering study was conducted at the Joint Water Pollution Control Plant (JWPCP) -- a 380 mgd primary treatment facility owned and operated by the Los Angeles County Sanitation Districts. Ocean discharge requirements on the effluent from this facility necessitated that at least 95 percent of the suspended solids be removed from the primary digested sludge for disposal by alternative means.

The applicability of heat, polymers, chemicals and flyash was investigated as a means of conditioning digested sludge for dewatering. Sludge dewatering schemes utilizing horizontal scroll centrifuges, imperforate basket centrifuges, vacuum filters and pressure filter were thoroughly studied. Operational results were obtained from twenty conditioning-dewatering test systems of which five successfully produced the desired suspended solids removal. Full scale cost estimates were prepared for each of the five systems.

Estimates were prepared for the requirements and costs associated with the ultimate disposal of dewatered sludges generated from each successful dewatering scheme. Three disposal alternatives were considered, namely, truck hauling of dewatered sludge from the JWPCP to a landfill; pipeline transport of digested sludge to a landfill with dewatering and disposal thereat; and incineration at the JWPCP with truck hauling of the ash residue to a landfill. Combining the disposal costs with the dewatering costs yielded estimates for fifteen total sludge handling systems. Remote area transportation and disposal costs were derived for comparative purposes.

It was concluded that a 2-stage centrifuge sludge dewatering scheme (polymer addition to the second stage) with truck hauling of dewatered sludge solids to a landfill was most suitable for the JWPCP. (Rodrigue-LACSD).

17a. Descriptors *Primary digested sludge, *Pollution abatement, *Sludge conditioning, *Sludge dewatering, *Sludge disposal, Heat treatment, Polymer addition, Chemical addition, Flyash addition, Sludge thickening, Horizontal scroll centrifuge, Imperforate basket centrifuge, Coil vacuum filter, Cloth belt vacuum filter, Pressure filter, Incineration, Landfill disposal, Pipeline transportation, Rail transportation, Lagooning, Land reclamation.

17b. Identifiers

*Los Angeles, *Sludge processing, Pilot study, Performance data, Cost estimates.

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SUMMARY REPORT: PILOT PLANT STUDIES ON DEWATERING PRIMARY DIGESTED SLUDGE

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ABSTRACT

During the interim from April, 1970 thru January, 1972 an extensive sludge dewatering investigation was conducted at the Joint Water Pollution Control Plant (JWPCP)--a 380-mgd (1.43 million-cu m/day) primary treatment facility owned and operated by the Los Angeles County Sanitation Districts. Discharge requirements imposed on the effluent from this facility necessitated that at least 95 percent of the suspended solids be removed from the primary digested sludge.

The applicability of heat treatment as a means of conditioning digested sludge for dewatering was investigated. Also considered were such conditioning aids as polymers, chemicals and flyash. Sludge dewatering schemes utilizing horizontal scroll centrifuges, imperforate basket centrifuges, vacuum filters and pressure filters were thoroughly studied. Operational results were obtained from twenty conditioning-dewatering test systems of which five successfully produced the desired suspended solids removal. Full scale cost estimates were produced for each of these five systems.

Estimates were prepared for the requirements and costs associated with ultimate disposal of dewatered sludges generated from each successful dewatering scheme. Three disposal alternatives were considered, namely, truck hauling of dewatered sludge from the JWPCP to a landfill; pipeline transport of digested sludge to a landfill with dewatering and disposal thereat; and incineration at the JWPCP with truck hauling of the ash residue to a landfill. Combining the disposal costs with the dewatering costs yielded estimates for fifteen total sludge handling systems. Remote area transportation and disposal costs were derived for comparative purposes.

It was concluded that a 2-stage centrifuge sludge dewatering scheme (polymer addition to the second stage) with truck hauling of dewatered sludge solids to a landfill was most suitable for the JWPCP.

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SUMMARY & CONCLUSIONS

The Los Angeles County Sanitation Districts conducted a 14-month pilot and plant scale sludge dewatering research program aimed at selecting a system to remove approximately 95 percent of the suspended solids contained in high rate anaerobically digested primary sludge. An existing dewatering system at the site of the research consisted of six 36-in. x 96-in. (91.4-cm x 243.8-cm) horizontal scroll centrifuges. During the course of the study both digested sludge and centrate from the existing centrifuges were used as feed to the various dewatering systems investigated. Based on the results of the research, cost estimates for dewatering and ultimate disposal of 300 dry tons ~~(272~~ metric ~~tons)~~ per day of wastewater solids were prepared.

The following conclusions have been drawn from the study:

Sludge Conditioning

1. High suspended solids recovery from digested sludge was not attainable without some form of conditioning. Acceptable results were obtained by the addition of polymers, lime and ferric chloride in various combinations.
2. Optimum dosage ranges per ton of solids were: cationic polymer, 3-10 lbs/ton (1.5-5.0 kg/metric ton); lime as $Ca(OH)_2$, 500-600 lbs/ton (250-300 kg/metric ton); ferric chloride, 80-120 lbs/ton (40-60 kg/metric ton).
3. Heat conditioning also produced sludges which could be dewatered on the experimental equipment. Optimal heat conditioning of digested sludge occurred at a temperature of 350^{o}F (175^{o}C) and a detention time of 40 minutes.
4. Gravity sedimentation of heat conditioned sludge was enhanced by picket thickening. The performance of a picket thickening clarifier on optimally heat-conditioned digested sludge was such that at an overflow of 225 gpd/sq ft (9.2 cu m/day/sq m), a decanted liquor

containing 3700 mg/l of suspended solids was obtained; higher overflow rates yielded increased concentrations of suspended solids in the decantate.

Dewatering: Horizontal Scroll Centrifugation

1. A 36-in. x 96-in. (91.4-cm x 243.8 cm) horizontal scroll centrifuge was operated at a bowl speed of 1300 rpm (900 gravities) and a differential speed of 15 rpm. Tests on unconditioned digested sludge produced the following results:

    a. At a constant feed rate, increasing the pool depth increased both suspended solids recovery and cake moisture content, while at a constant pool depth, solids recovery decreased and cake dryness increased with increasing feed rate.

    b. The maximum solids recovery attainable was 55 percent at a feed rate of 200 gpm (12.6 l/sec) and a maximum pool depth setting of 3.4 inches (8.6 cm); dewatered sludge cake was 21% solids by weight.

2. Under the same machine operating conditions as listed above, cationic polymer conditioning at a constant feed rate of 250 gpm (15.8 l/sec) in the 36-in. x 96-in. (91.4-cm x 243.8-cm) horizontal scroll centrifuge produced the following results:

    a. The highest solid recovery was achieved when polymer was injected into the sludge stream within the bowl of the centrifuge; polymer injection into either the suction or discharge lines of the feed pump yielded lower recovery.

    b. Apparent changes in the characteristic of digested sludge from day to day influenced the ability of polymers to enhance suspended solids capture in the centrifuge. Results obtained under identical operating conditions were unpredictable.

    c. Under responsive sludge conditions the polymer dosage necessary to achieve 95 percent solids recovery was about 10 lbs/ton (5.0 kg/metric ton); dewatered sludge cake was 20% solids by weight.

3. Using a 6-inch (15.2-cm) diameter pilot scale horizontal scroll centrifuge, a maximum suspended solids

removal of 81 percent was obtained with a system employing heat conditioning of digested sludge followed by horizontal scroll centrifugation; the same system obtained about 90 percent removal with the addition of 3.5 lbs/ton (1.75 kg/metric ton) of polymer to the bowl of the centrifuge. In both cases, generated cakes were 31% solids by weight.

4. Dewatering of digested sludge--heat conditioned and thickened--in a 6-inch (15.2-cm) diameter horizontal scroll centrifuge yielded a suspended solid removal of 85 percent; about 91 percent removal was experienced with the addition of 3.0 lbs/ton (1.5 kg/metric ton) of polymer to the centrifuge bowl; cake solids were approximately 25% by weight.

Dewatering: Basket Centrifuges

1. Without sludge conditioning, tests conducted with a basket centrifuge operated at 1300 gravities and fed centrate from the existing horizontal scroll centrifuges revealed that:
   a. Average solids recovery varied inversely with feed rate.
   b. A maximum solids recovery of 80 percent was attained; corresponding cakes were at 8% solids by weight.
2. Tests conducted with cationic polymer conditioning of centrate fed to a basket centrifuge revealed:
   a. Solids recovery was highest when the polymer solution was sprayed into the sludge stream within the bowl; polymer injection into either the suction or discharge lines of the feed pump yielded lower recoveries.
   b. With a polymer dosage above 1-2 lbs/ton (0.5-1.0 kg/metric ton), a solids recovery of 95 percent was obtained. Recovery was not greatly affected by increased feed rates.
   c. At a given feed rate, increased polymer dosages served to increase the duration of the feed cycle which resulted in increased cake dryness.
   d. Optimum results indicated that the basket centrifuge could capture 95 percent of the suspended solids from the centrate of the horizontal scroll

centrifuge, producing a cake of about 20% solids by weight. A polymer dosage of 4 lbs/ton (2 kg/metric ton) was required to obtain this performance.

e. A system of basket centrifuges in series with horizontal scroll centrifuges yielded an effluent containing 1500 mg/l or less of suspended solids and generated cakes (1st and 2nd stage blends) of 25% solids by weight; a polymer dosage of 4 lbs/ton (2 kg/metric ton) is added to the basket centrifuge.

Dewatering: Vacuum Filters

1. Vacuum coil filtration tests on digested sludge revealed that:

    a. With polymer conditioning, consistent suspended solids recovery of 95 percent was only achieved with dosages of 10 lbs/ton (5 kg/metric ton) or more; erratic recovery occurred at lesser dosages.

    b. At a polymer dosage of 10 lbs/ton (5 kg/metric ton), solids recovery and generated cake (18% solids by weight) remained unaffected by variations in solid loading rates up to 18 lbs/hr/sq ft (87.8 kg/hr/sq m).

    c. With lime and ferric chloride conditioning, suspended solids capture varied inversely with solids loading rate, although cake dryness (about 25% solids by weight) was relatively unaffected.

    d. A maximum solids recovery of 92 percent was experienced at a solids loading rate of 1.5 lbs/hr/sq ft (7.3 kg/hr/sq m) and a lime, as $Ca(OH)_2$, and ferric chloride dosage of 600 lbs/ton (300 kg/metric ton) and 80 lbs/ton (40 kg/metric ton), respectively; greater or lesser amounts of ferric chloride or lesser amounts of lime produced inferior results.

    e. A maximum suspended solid recovery of 70 percent was experienced from a system employing heat conditioning, thickening and filtration of digested sludge at a solids loading rate of 3 lbs/hr/sq ft (14.6 kg/hr/sq m); cake solids were approximately 31% by weight.

2. Rotary-belt vacuum filtration tests on digested sludge revealed that:
    a. When polymer conditioning was attempted, rapid blinding of the filter media occurred.
    b. With lime conditioning, suspended solids recovery in excess of 99 percent was achievable at a lime dosage of 600 lbs/ton (300 kg/metric ton) as $Ca(OH)_2$ and a maximum solids loading of 1.5 lbs/hr/sq ft (7.3 kg/hr/sq m); generated cakes were 35% solids by weight. This performance was not enhanced by the inclusion of ferric chloride conditioning.
    c. A system employing heat conditioning and thickening prior to filtration produced a maximum suspended solids removal of 92 percent and, correspondingly, discharged cake having a solids content of 37% by weight; the maximum solids loading rate to the filter was 3.3 lbs/hr/sq ft (16.1 kg/hr/sq m).

Dewatering: Pressure Filter

1. Rapid blinding of the filter media occurred when cationic polymers were used as the conditioning aid.
2. When chemical (lime and ferric chloride) or ash conditioning was employed, the resulting filtrates generally contained less than 100 mg/l of suspended solids; increasing the length of the feed cycle effected an increase in cake dryness and a corresponding decrease in the overall solids loading.
3. For a particular lime dosage and feed time, drier cakes were generated as the ferric chloride dosage was increased up to 120 lbs/ton (60 kg/metric ton).
4. With chemical conditioning, optimum performance was achieved with a 2-hour run time and a lime, as $Ca(OH)_2$, and ferric chloride dosage of 500 lbs/ton (250 kg/metric ton) and 120 lbs/ton (60 kg/metric ton), respectively; generated cakes were 40% solids by weight.
5. Ash conditioning was most successful when a small amount of lime was included for raising the pH;

optimum performance was acheived with an ash dosage of 4000 lbs/ton (2000 kg/metric ton).

6. Using a diatomaceous earth precoat, pressure filtration of heat conditioned sludge yielded filtrates containing less than 100 mg/l of suspended solids; generated cakes were 30% solids by weight but discharged poorly from the filter cloth media.

7. Although pressure filtration of thickened, heat conditioned sludge produced cakes (38% solids by weight) having excellent discharge properties, the combined effluent (filtrate plus thickener overflow) from such a system contained 3100 mg/l of suspended solids.

Disposal

1. Truck hauling of dewatered sludge to a landfill, pipeline transport of digested sludge to a landfill with subsequent dewatering at the landfill, and incineration with ash hauling to a landfill were considered for ultimate sludge disposal. Preliminary investigations indicated thatultimate disposal of sludge to the land via soil reclamation or lagooning could also hold promise as a long term sludge disposal scheme.

2. Although there may be some minor economic advantages to be gained from incineration, the potential air pollution problems associated with incineration were such that the process was not considered to be a feasible solution for ultimate sludge disposal in the Los Angeles Basin.

3. The lack of sufficient technical knowledge concerning soil reclamation or lagooning preclude these disposal methods from immediate consideration.

Costs

1. Estimates for dewatering and disposal were based on 300 dry tons/day (272 metric tons/day). This number was selected as representing existing sludge quantities and was used for comparative purposes. Actual quantities used in the design of a full scale system are higher than 300 tons/day (272 metric tons/day). A 10-year life was assumed for all equipment for purposes of capital amortization at 6%.

2. Cost estimates for the five combinations of sludge conditioning and dewatering which met the established criteria indicated the unit cost ranged from $11.10/ton ($12.20/metric ton) for a two-stage centrifugation system utilizing polymer conditioning in the second stage to $28.30/ton ($31.20/metric ton) for a pressure filtration system using lime and ferric chloride as conditioning agents.

3. The cost of truck hauling of dewatered sludge to a landfill varied directly with the quantity of sludge to be hauled. Total cost varied from $10.90/ton ($12.00/metric ton) for heat conditioned, gravity thickened, vacuum filtered sludge to $23.00/ton ($25.40/metric ton) for the polymer conditioned, vacuum filtered sludge.

4. Combining dewatering and truck hauling estimates yielded costs ranging from $29.10/ton ($32.10/metric ton) for a two-stage centrifuge system to $44.00/ton ($48.50/metric ton) for a pressure filtration system.

5. Cost estimates for pipeline transport to a landfill varied from $15.25/ton to $22.10/ton ($16.80/metric ton to $24.40/metric ton).

6. Combining dewatering estimates with the pipeline transport scheme for disposal yielded costs ranging from $29.50/ton ($32.50/metric ton) for heat conditioning, gravity thickening, vacuum filtration dewatering to $44.80/ton ($49.40/metric ton) for pressure filtration of lime and ferric chloride conditioned sludge.

7. Incineration costs ranged from $8.30/ton to $24.50/ton ($9.20/metric ton to $27.00/metric ton). These estimates were based on certain assumed air pollution control equipment.

8. The most economical sludge processing system for the JWPCP based on cost estimates for dewatering and disposing of 300 dry tons/day (272 metric tons/day) was a two-stage centrifuge system utilizing polymer conditioning in the second stage with disposal by truck hauling to a landfill.

System Selection

1. A two stage centrifuge system utilizing polymer conditioning was selected as the dewatering system for the JWPCP because:

   a. The system produced very reliable results throughout the study.
   b. A two stage system will allow continued use of the horizontal scroll system which offers the advantage of familiarity of operation on the part of the JWPCP staff.
   c. It provides the lowest total cost system of those meeting the quality criteria.

2. Truck hauling to a landfill was selected over pipeline transport to the landfill for the following reasons:
   a. The lower capital cost and greater flexibility of a truck hauling system.
   b. The pipeline system would have required too long a time period to construct.
   c. The dewaterability of the digested sludge when it reached the landfill via pipeline was unknown.

INTRODUCTION

One of the most difficult aspects of wastewater treatment today is the processing and disposal of sewage sludges. A large portion of the waste treatment methods in use throughout the country only serve to concentrate the incoming pollutional material into a reduced portion of the total waste flow. Assuming that discharge standards are met, this permits easy disposal of the bulk of this flow to a natural water environment. It is the residual concentrate, i.e. the sludge remaining, which must undergo additional and more refined processing prior to being acceptable for discharge into one of nature's reservoirs.

Numerous processes or combinations thereof are being used throughout the country for treating and handling wastewater sludges. Typical among these are such processes as sludge thickening; aerobic digestion; conventional or high rate anaerobic digestion; elutriation; sludge conditioning with chemicals, polymers, flyash, heat, etc; lagooning; mechanical dewatering; dehydration; and incineration. In any particular treatment facility, the applicability of a sludge handling step is primarily dependent on the sludge type, its physical and chemical makeup, and the character of the wastewater from which the sludge was derived. Of course, the overall success of any sludge handling scheme depends on how well each process is selected and combined with one another in order to meet the disposal requirements of a particular situation.

The use of anaerobic digestion to stabilize and render sludges innocuous for final disposal is practiced at many wastewater treatment plants including the Joint Water Pollution Control Plant (JWPCP)--a coastal, primary treatment facility owned and operated by the County Sanitation Districts of Los Angeles County, hereinafter referred to as the "Districts". Prior to 1959, the waste digested sludge from this facility was processed on open drying beds located adjacent to the plant. Increasing residential and commercial growth coupled with the difficulty of maintianing a nuisance-free operation led to the eventual abandonment of this practice.

Present treatment operations at the JWPCP provide for sludge handling in the following manner. Raw primary sludge (6% solids) is pumped into digesters wherein it is subjected to high-rate anaerobic decomposition. Following an 11 to 12-day digestion period, waste digested sludge (4% solids) undergoes partial dewatering by means of solid bowl centrifugation. The centrifuged effluent, hereinafter referred to as centrate, is screened to remove large-sized floatable material. The screened centrate is processed through a sludge washing tank to remove any floatable material remaining. Approximately 30 percent of the suspended material is removed from the digested sludge by centrifuging, screening and washing prior to ocean discharge. The dewatered solids (centrifuged cake and centrate screenings) are spread on adjacent acreage and allowed to air dry; this material is then taken by a fertilizer company for incorporation into various fertilizer products.

Throughout the 1960's, the discharge of centrate to the marine environment had been acceptably practiced at the JWPCP. During that period, the ocean waters adjacent to the outfall discharge point were monitored to insure that the water quality standards placed on the receiving body were being met.

In September of 1970 the Los Angeles Regional Water Quality Control Board promulgated new standards on the effluent being discharged to the ocean from the JWPCP. It was readily apparent that compliance with the new edict would require a major supplementation to the existing treatment facilities. Additional primary clarifier capacity would be needed to bring about greater suspended solids removal from the incoming wastewater stream. Moreover, the new standards mandated a criterion for a sludge dewatering system which would be capable of recovering at least 95 percent of the suspended material from the waste digested sludge stream, i.e. the effluent from such a system would be expected to contain no more than 1500 mg/l of suspended solids.

Consideration was then given to the sludge quantities involved at the JWPCP, to the complexities and anticipated high costs associated with solids capture to the extent demanded, and to the alternatives available for dewatered solids disposal. One of the first decisions that had to be made was whether or not to retain anaerobic digestion as an integral part of the sludge handling system. Despite the fact that raw sludges were known to be more easily dewatered, the Districts decided in favor of digestion in view of the extensive commitment already made to that process at the JWPCP.

The Districts approach to the sludge problem was threefold. First, methods of additional dewatering of the centrate material from the existing horizontal scroll centrifuge station would be sought out. This would provide the advantage of utilizing dewatering equipment already installed and also offer the potential to continue the supply of solids for fertilizer production. The second approach was to investigate dewatering schemes which would not incorporate usage of the existing centrifuge station. Finally, an analysis of each of the successfully contrived dewatering schemes would be made along with the alternatives for dewatered solids disposal so as to arrive at the most practical and economical means of solving the problem.

Beginning in November 1970, the manufacturers of various sludge conditioning products and sludge dewatering equipment were sought out regarding the applicability of their merchandise to the sludge problem at the JWPCP. A study was conducted to determine the dewatering capabilities of the existing solid bowl centrifuge station as influenced by variations in several parameters. Promising sludge conditioners and other dewatering equipment were evaluated on a pilot plant scale. Each dewatering unit was evaluated by itself and in conjunction with one another as a total system.

A research site was constructed on the premises of the JWPCP to accomodate the pilot plant units. A small chemical station was built for batching polymers into solution. Also, one of the existing solid bowl centrifuges was isolated and rigged for test purposes. By January of 1971, the 2-year research program was underway.

The following is a report on the results of the piloted research work conducted at the JWPCP. Details are presented on the performance of each of the conditioning-dewatering systems investigated. Of the many schemes evaluated, five were selected which, in addition to meeting the effluent requirements, were judged to provide a practical and economical solution to the problem. In this regard, full scale cost estimates were prepared for each and are presented herein.

Consideration was then given to the manner in which dewatered solids could be ultimately disposed of. For each of the five chosen dewatering schemes, cost estimates were prepared for the ultimate disposal of these solids by three methods, namely

(1) Landfilling, with pipeline transport of primary digested sludge to a landfill for dewatering and solids disposal;

(2) Landfilling, with truck transport of the dewatered solids from the JWPCP to a landfill;

(3) Incineration at the JWPCP with truck transport of the ash to a landfill.

These costs are also presented in this report. The alternative costs of the five dewatering schemes and three disposal schemes were then combined to provide fifteen total system cost alternatives. This, along with other intangible criteria, enabled the Districts to select a sludge management system most suitable for their situation.

In addition to the above, a brief study was made of the costs for remote disposal of JWPCP's digested sludge. The estimates were made to aid in the selection of a dewatering process which might prove to be compatible with some future sludge disposal scheme utilizing a remote area. These estimates are presented and discussed in this report.

SANITATION DISTRICTS' WASTEWATER SYSTEM

The County Sanitation Districts of Los Angeles County is comprised of 26 individual districts. As a combined group they form one of the largest systems in existence today. At present, the Districts provide service for 71 incorporated cities and several large tracts of unincorporated land. Together, they constitute a 730 sq mile (1891 sq km) area from which 450-mgd (1.70 million cu m/day) of wastewater is derived. The collective population being served in this area is now approaching 4 million people. The Districts handle 70 percent of the total industrial wastewater load generated within Los Angeles County which amounts to about 180 mgd (0.68 million cu m/day). Thus, 40 percent of the municipal wastewater managed by the Districts is of industrial origin. Characteristically then, the overall wastestream is quite atypical and, in many respects, is difficult to treat.

At present, the Sanitation Districts manages and operates eleven wastewater treatment facilities, the largest of which is the Joint Water Pollution Control Plant (JWPCP) -- a 380-mgd (1.43 million cu m/day) primary treatment facility located in the City of Carson, California. The JWPCP is situated in the southern part of Los Angeles County approximately 6 miles (9.7 km) from the Pacific Ocean. The other 10 treatment plants -- secondary treatment facilities which, within their own respective capacity, process wastewater flows ranging from 0.3 to 31 mgd (1100 to 117,300 cu m/day)-- collectively handle the remaining 70 mgd (0.27 million cu m/day) and are situated more inland and further to the north. Five small inland plants provide separate treatment and disposal of their own generated sludges. The other five plants, which collectively process 63 mgd (0.24 million cu m/day) of wastewater, each discards its accumulated raw primary and secondary sludges into the sewer system which ultimately terminates at the JWPCP. The sludge solids load imposed on the JWPCP treatment facility, therefore, represents that derived from 443 mgd (1.68 million cu m/day) of wastewater flow, that being 98.4 percent of the Districts' total wastewater responsibility.

DESCRIPTION OF THE JWPCP SYSTEM

The Joint Water Pollution Control Plant has been in operation since about 1935. Since that time, Los Angeles County has experienced considerable dynamic growth in both population and industry. To cope with this, the JWPCP has had to be periodically expanded and augmented to provide sufficient capacity and treatability for the increased wastewater flow.

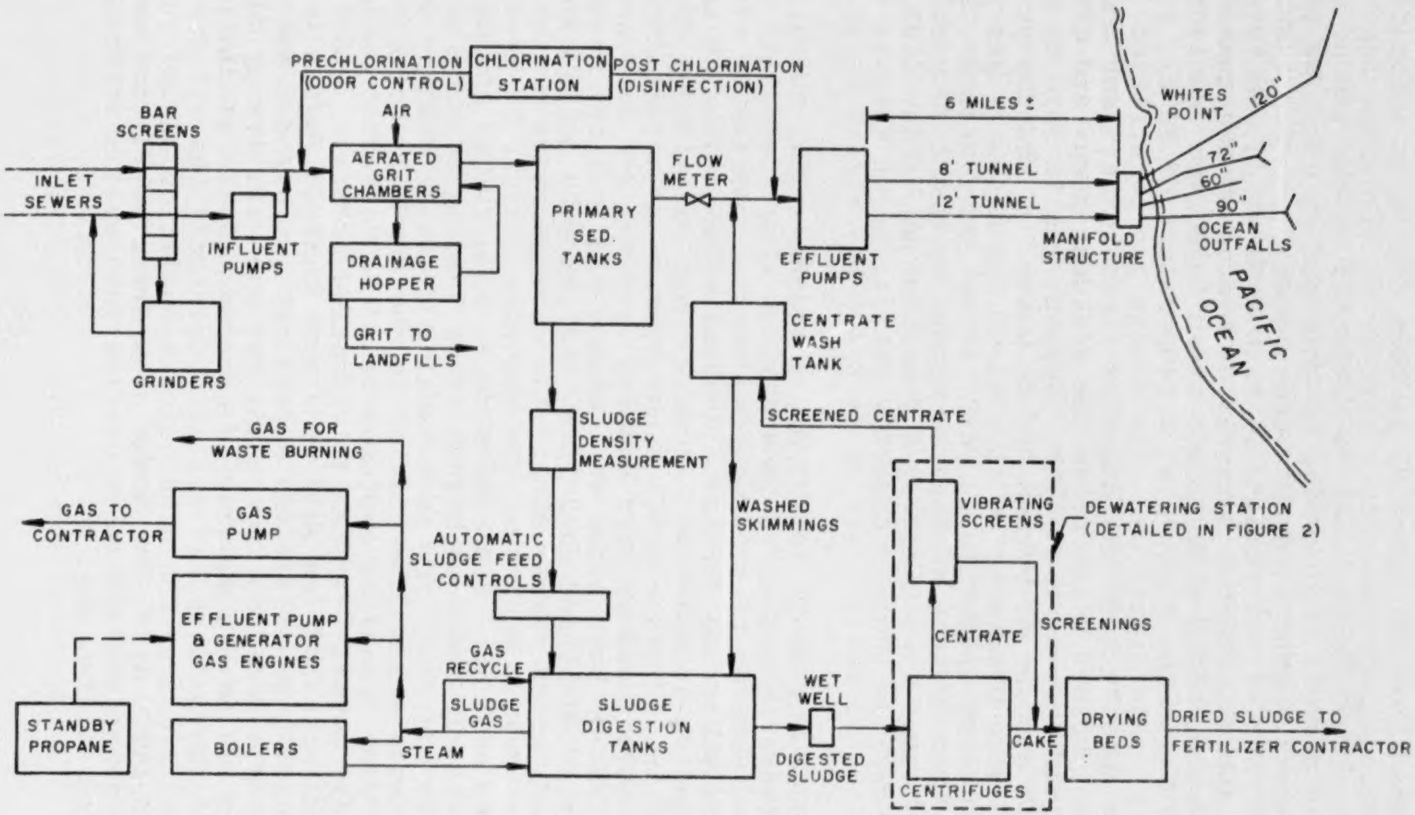
The sewerage system tributary to the JWPCP consists of a vast network of interceptors and trunk lines which carries domestic wastewater from the dwellings of nearly 4 million people. An estimated 30,000 industries and commercial establishments are serviced by the network. In certain areas, the system is also utilized for the disposal of oil brine wastes. Upon reaching the terminus, 380 mgd (1.43 million cu m/day) of a highly mineralized waste mixture enters the JWPCP for treatment.

Figure 1 is a schematic of the existing treatment and disposal system at the JWPCP. Wastewater flows into the plant through several trunk sewers. From the inlet works, it is introduced to a parallel system of fixed bar screens for removal of coarse-sized suspended material. Automechanical rakes remove the trapped screenings from within the flowstream. The rakings are conveyed to a parallel system of grinders, ground to smaller fractions, and reintroduced into the plant influent for precautionary rescreening. The effluent passing through the screens is hydraulically lifted when necessary, prechlorinated for odor control, and then directed to a system of aerated grit chambers wherein the flow through velocity is sufficiently reduced to facilitate the sedimentation of grit. Dispersed air bubbles serve to scrub the descending grit free of lighter organic material. Settled grit is continuously scraped from the bottom of each chamber, conveyed into a drainage hopper, and later hauled by truck to a landfill for disposal. The effluent from the grit chambers is channeled into a network of primary sedimentation tanks which have a detention time of approximately one hour. Primary effluent is directed to the effluent pump works to be transported to the ocean for disposal.

The pumping of raw sludge from the primary sedimentation tanks is controlled by radioactive density meters. The control is such that a raw sludge mixture of about 6% suspended solids concentration (60,000 mg/l) is maintained during

FIGURE I

Schematic flow diagram
Joint Water Pollution Control Plant

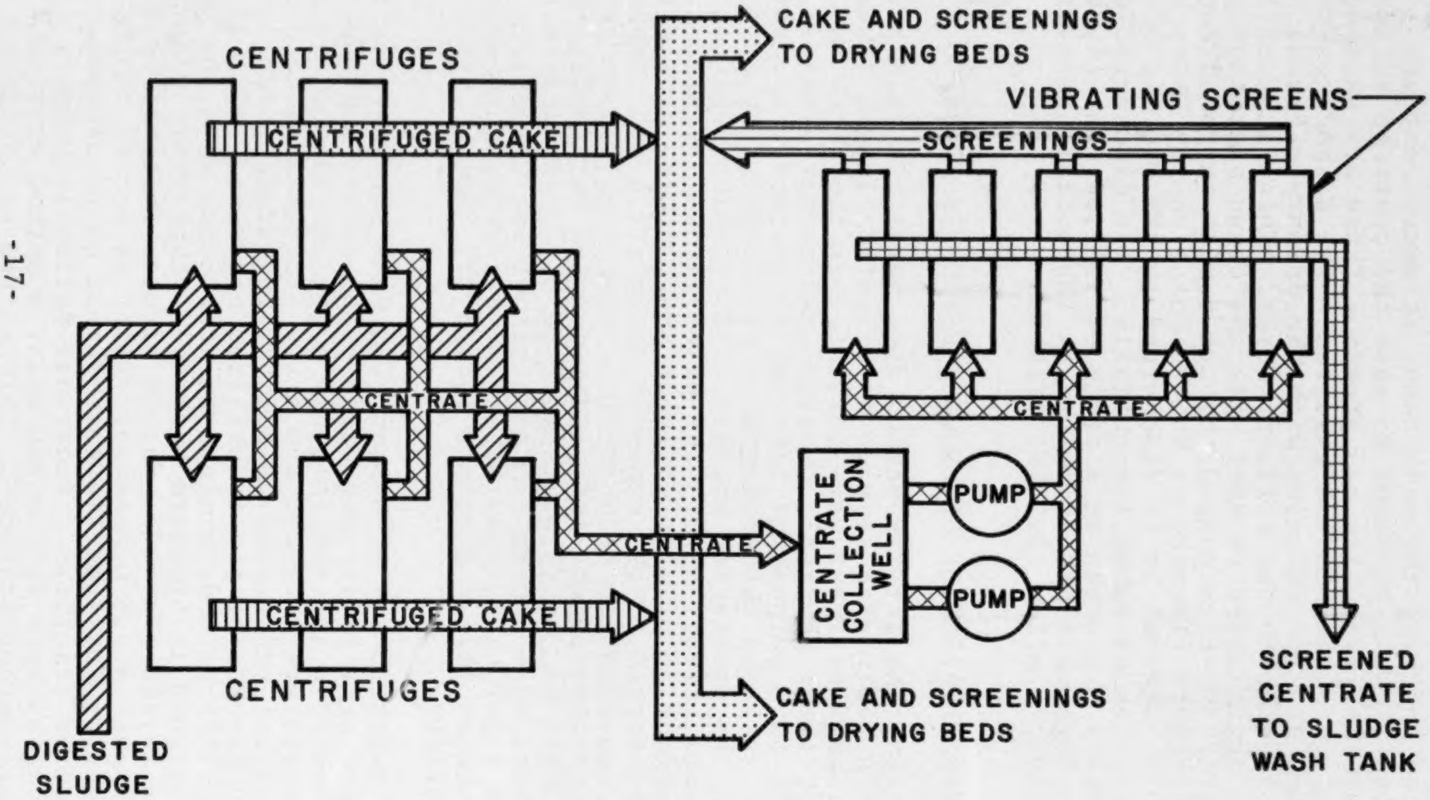


removal. This material is then fed in an automatically prearranged manner to a battery of high-rate anaerobic digestion tanks. Gas is collected at the top of each tank for drawoff. A portion of this gas is recycled through several vertical draft tubes located in each tank. A gas lifting effect results in each tube which, in turn, imparts a slow continuous turnover or mixing of the tanks' contents. Mixing, along with direct steam injection (controlled to maintain the mixture at a temperature of 94°F), produces high rate digestion. The sludge gas is utilized for fuel to operate both the digester steam boilers and the large gas engines which drive the effluent pumps and electrical generators at the JWPCP. Surplus gas is sold to an adjacent oil company or burned off as waste. A standby propane supply is also available to supplement the digester gas fuel. The digester operation at JWPCP effectively reduces the volatile matter content of the raw sludge by about 50 percent and produces approximately 5.2 million cu ft/day (145,600 cu m/day) of useable digester gas having an average heat value of 600 BTU/std cu ft (5400 kg-cal/std cu m).

Following an 11- to 12-day residency time, the digested sludge is collected in a holding tank (wet well) for controlled pumping to a dewatering station consisting of centrifuges and vibrating screens. A detailed schematic of this station is shown in Figure 2. Six centrifuges (36-in. x 96-in. (91.4-cm x 243.8-cm) horizontal scroll decanter type manufactured by Bird Machine Company) are arranged 3 in a row on both sides of a common pipe gallery containing the digested sludge feed line, the centrate drain line and a wash water supply line. The configuration of the piping network is such that the machines operate in parallel to one another. Digested sludge, pumped from the sludge wet well, is fed into branch lines leading to each centrifuge. The centrate from each machine flows by gravity into a common drain line leading to the centrate collection well. A pump transfers centrate from the collection well to a parallel operating system of vibrating screens. Gravity flow of the screened centrate to a wash tank follows. The centrifuged cake solids and screenings are blended and conveyed into a truck for spreading and open air drying on land adjacent to the dewatering station. Daily mechanical turning of the land spread solids accelerates the air drying process and provides enhanced aerobic conditioning and reduced odor levels. After one month, the dried solids are removed by a contractor for incorporation into soil conditioning fertilizer products.

FIGURE 2

Schematic flow diagram of sludge dewatering station



Upon entering the wash tank, screened centrate is elutriated with 2 parts of water to wash the centrate solids free of surplus floatables and grease. These are skimmed off and recycled back to the digester. The washed centrate is then directed for dilution with the primary effluent being channeled to the effluent works. This final effluent blend is chlorinated to meet with the ocean bacteriological standards and then pumped through 6-mile tunneled conduits to a structure (located at Whites Point on the Palos Verdes Peninsula) whereat it is discharged to the Pacific Ocean through a system of submarine outfalls. The discharged effluent enters the ocean at a depth of 150-200 feet (46-61 meters) through multiple diffusers at the outfall termini, approximately 2 miles (3.2 km) offshore.

CHARACTERIZATION OF PROCESS EFFLUENTS AT JWPCP

During the interim period from April 27, 1970 to August 18, 1970 daily grab samples of digested sludge, centrate and primary effluent were collected at the JWPCP and analyzed for their physical, chemical and bacteriological makeup. The main purpose of this was to characterize centrate, to evaluate the performance of the existing centrifuges at the dewatering station, and to quantitatively and qualitatively assess the proportional ingredient contributions of primary effluent and centrate when blended and discharged to the ocean as plant effluent. Because of the large quantity of analytical work required to completely characterize the individual samples collected, only a small number of constituents were selected for determination. These were chosen on the basis of their relative importance as a polluting agent, ease of determination, degree of fitness into the normal laboratory routine, and interrelateability.

A quantitative assessment was made for total solids, including volatile and fixed components; suspended solids; floatable and nonfloatable suspended solids, including the respective volatile and fixed fractions of each; settleable solids; and dissolved solids, including volatile and fixed components of the solubilized material. Most of these factors were determined in accordance with the procedures outlined in Standard Methods[1]. Laboratory centrifugation at 28,800 gravities for 15 minutes followed by filtration through a 0.8 μ membrane filter served to fractionate the samples for separate measurement of the suspended and dissolved fractions. Floatable solids in primary effluent samples were determined using a method developed by Engineering Science[2]. This method was modified somewhat in order to measure this factor in the digested and centrate sludge samples. Settleable solids in the sludge samples were indirectly determined utilizing dilution techniques.

Chemical characterization included an analysis of each sample for biochemical oxygen demand (BOD); chemical oxygen demand (COD); organic, ammonium, nitrate and nitrite nitrogen; total phosphorous; sulfide, sulfate and thiosulfate; phenols and cyanide; alkalinity and hydrogen ion concentration (pH); oxidation-reduction potential (ORP); and 30-minute chlorine demand. In addition, samples were analyzed for their total grease content, i.e. for the amount of material extractable by hexane. For the most part, the above chemical analyses were run on each sample both before and after suspended solids removal. This enabled the chemical load of each effluent to be separated into that contributed by either the suspended or dissolved solids fraction.

Presented in Table 1 are tabulated averages of all compiled solids data acquired from the analysis of daily grab samples of primary effluent, digested sludge and centrate taken during the 4 month surveillance study of the JWPCP process effluents. A similar tabulation of the chemical and bacteriological data averages for these samples is presented in Table 2. In both tables, corresponding data are presented to reflect the concentration of each constituent in the plant effluent -- that effluent being a blend of 380 mgd (1.43 million cu m/day) of primary effluent with 1.8 mgd (6,800 cu m/day) of centrate from the dewatering station. These latter data are calculated values based on the respective daily flows of the two component effluents.

A correlative comparison of the suspended and dissolved solid averages of Table 1 with the chemical data averages of Table 2 provided the Districts with the following observed information.

(1) More than 90 percent of the total COD, BOD, organic nitrogen, total phosphorous and chlorine demand in centrate and digested sludge were attributable to the suspended solids of each.

(2) The grease content in digested and centrate sludge was found to comprise a sizeable portion (approximately 20 to 25 percent) of the total solid load of each.

Table 1: AVERAGE SOLIDS MAKEUP OF VARIOUS PROCESS EFFLUENTS AT JWPCP*
-mg/1-

FACTOR MEASURED \ SAMPLED MATERIAL	DIGESTED SLUDGE	CENTRATE	PRIMARY EFFLUENT	PLANT EFFLUENT***
TOTAL SOLIDS	41,330	30,302	2,069	2,202
A. Total Volatile Solids	23,241	18,460	550	634
B. Total Fixed Solids	18,089	11,842	1,519	1,568
C. Total Suspended Solids	38,852	27,898	176	307
1. Floatable Suspended	241	110	1	~1
a. Volatile	93	92	1	~1
b. Fixed	148	18	0	~0
2. Nonfloatable Suspended	38,611	27,788	175	306
a. Volatile	22,352	17,453	78	160
b. Fixed	16,259	10,335	97	146
D. Total Dissolved Solids	2,478	2,404	1,893	1,895
1. Volatile Dissolved	796	915	471	473
2. Fixed Dissolved	1,682	1,489	1,422	1,422
E. Settleable Solids**	~1,000	~1,000	1.7	4.0

*JWPCP data based on daily averages (April-August, 1970)

**Units for settleable solids are ml/1

***The plant effluent from JWPCP is a combined blend of 380 mgd of primary effluent and 1.8 mgd of centrate from the sludge dewatering station. Tabulated values are calculated on this basis.

Unit Conversions: (mgd) x 3,785 = (cu m/day)

Table 2: AVERAGE CHEMICAL COMPOSITION AND 'MPN' CONTENT IN VARIOUS PROCESS EFFLUENTS AT JWPCP†

SAMPLED MATERIAL / FACTOR MEASURED	DIGESTED SLUDGE		CENTRATE		PRIMARY EFFLUENT		PLANT EFFLUENT**	
	Average Total	Average Soluble	Average Total	Average Soluble	Average Total	Average Soluble	Average Total	Average Soluble
BOD (mg/1 O)	4,702	261	4,396	285	284	216	303	216
COD (mg/1 O)	38,996	498	21,333	701	452	335	551	337
Organic Nitrogen (mg/1 N)	1,061	50	863	86	31	24	35	24
Ammonia Nitrogen (mg/1 N)	487	470	420	401	42	40	44	42
Nitrite Nitrogen (mg/1 N)	*	0.0	*	0.0	*	0.0	--	0.0
Nitrate Nitrogen (mg/1 N)	*	0.2	*	0.2	*	0.2	--	0.2
Total Phosphorous (mg/1 P)	238	3.3	204	3.0	7.2	3.6	8.1	3.6
Sulfide (mg/1 S)	100	0.0	92	0.0	0.0	0.0	0.4	0.0
Sulfate (mg/1 SO_4)	*	--	*	15	*	389	--	387
Thiosulfate (mg/1 S_2O_3)	--	--	8	0	131	97	130	97
Phenols (mg/1 C_6H_5OH)	2.8	1.8	2.5	1.4	6.5	4.9	6.5	4.9
Cyanide (mg/1 CN)	0.09	--	0.05	--	0.2	--	0.2	--
Alkalinity (mg/1 $CaCO_3$)	5,246	2,927	5,024	2,580	359	355	381	366
pH (pH units)	7.1	7.8	7.5	8.0	8.2	8.1	8.2	8.1
30-min Cl Demand (mg/1 Cl)	2,556	22	2,208	20	69	60	79	60
ORP (millivolts)	-210	+40	-214	+50	-20	-3	--	--
MPN (No./ml)	4.1×10^6	--	1.8×10^6	--	1.8×10^6	--	1.8×10^6	--
Grease (mg/1 Hex. Ext.)	8,354	--	7,762	--	44	--	81	--

* Not feasible to evaluate by standard laboratory methods.

** Plant effluent from JWPCP is a combined blend of 380 mgd of primary effluent and 1.8 mgd of centrate from the sludge dewatering station. Tabulated values are calculated on this basis.

† JWPCP data based on daily averages (April-August, 1970)

Unit Conversions: (mgd) x 3,785 = (cu m/day)

(3) The relative contribution of the suspended solids in centrate to the settleable solids in the JWPCP plant effluent was approximately 3.0 ml/l; that from primary effluent was 1.0 ml/l.

(4) The total average grease load in the plant effluent from the JWPCP was calculated to be 81 mg/l of which 44 mg/l was from the primary effluent and the remaining 37 mg/l was contributed by the centrate.

(5) On the average, approximately 30-31% of the suspended solids were removed or captured by the centrifugal sludge dewatering process; the remainder was being discharged to the ocean.

(6) The addition of centrate to the primary effluent significantly increased the suspended solids, total BOD, COD, and chlorine demand.

In addition to the above, two important observations were made with regard to the data acquired from each individual sample (individual sample data not presented herein). First, the physical and chemical consistency of digested sludge remained relatively constant throughout the 4-month monitoring period whereas that of centrate did not. Evidently, centrifuge performance at the dewatering station was irregular. Second, total grease was a varying factor in both centrate and digested sludge but remained relatively constant in primary effluent.

The suspended solid, settleable solid and BOD data averages from Tables 1 and 2 for centrate, primary effluent and JWPCP plant effluent are retabulated in Table 3. Also tabulated are the numerical limits placed on these three parameters by the discharge standards issued in September of 1970 by the Los Angeles Regional Water Quality Control Board (WQCB). Quite clearly, these data revealed that the primary effluent itself did not meet the requirements and would therefore have to be upgraded. Moreover, it was apparent that the centrate solids contributed substantially toward the inferior quality of the plant effluent and that compliance with the new standards would necessitate a sizeable removal of the material from the sludge effluent stream.

Table 3: EFFLUENT QUALITIES* AND EFFLUENT QUALITY REQUIREMENTS AT JWPCP

LOCATION PARAMETER	CENTRATE	PRIMARY EFFLUENT	PLANT EFFLUENT	
			Existing**	WQCB Discharge Requirements***
Biochemical Oxygen Demand (BOD) -mg/1-	4,396	284	303	250
Suspended Solids -mg/1-	27,898	176	307	200
Settleable Solids -ml/1-	~1,000	1.7	4.0	1.0

*JWPCP data based on daily averages (April - August, 1970)

**Plant effluent from JWPCP is a combined blend of primary effluent (currently 380 mgd) and centrate (currently 1.8 mgd) from the sludge dewatering station. Tabulated values are calculated on this basis.

***WQCB requirement for BOD and suspended solids based on monthly average of daily samples; settleable solids requirement based on daily sample.

Unit Conversions: (mgd) x 3,785 = (cu m/day)

BACKGROUND INFORMATION SUMMARY

In retrospect, the overall problem at JWPCP seemed to be one of solids removal. The Districts' decision to add fourteen new sedimentation tanks to the existing capacity at the JWPCP was deemed sufficient for removing the additional suspended material necessary to reduce the overall BOD and settleable solids to levels acceptable for discharge. In conjunction with this, however, the digested sludge would necessitate dewatering to the extent of removing 95 percent of its suspended solid load. This appeared to be a reasonable course to pursue but a difficult task to accomplish in view of the following:

(1) The high quantity of sludge necessitating dewatering (1.8 mgd) (6800 cu m/day).

(2) The atypical nature of this sludge as a result of the high industrial component.

(3) The fineness of the sludge solids as a result of attrition in the digesters and in the vast sewerage system tributary to the JWPCP.

The selection of any dewatering scheme to achieve these desired end results would be dictated by the economics of that process and the means by which the recovered solids might be disposed of. Achieving high solid recoveries would simply mean capturing more of the finely suspended particulate matter from the digested sludge slurry. Because of the high ratio of biologically bound water associated with these fines, the additional capture would certainly lead to a cake of considerably greater moisture content than that presently obtained. Moreover, if some form of sludge conditioning were required to attain the desired degree of dewaterability, its use might render the recovered solids useless for fertilizers. Hence, alternative means of solids disposal would have to be sought out.

If landfill disposal were selected, then the dewatered cake solids would have to be sufficiently devoid of moisture for truck hauling and landfill handling. The Districts' refuse department had estimated that 75% moisture or less would be suitable in this respect. However, the economics of hauling versus moisture removal would dictate the desired constituency of the final cake product. A dewatering system capable of removing 95 percent of the suspended solids from the digested sludge stream would result in approximately 300 tons/day (272 metric tons/day) of dry solids requiring disposal. At 25% solids concentration by weight, this would necessitate hauling about 1200 tons (1088 metric tons) of wet material per day. Despite these large tonnages, landfill disposal would seemingly appear attractive in view of the nearby location of the Districts' operated Palos Verdes Landfill, approximately 4 miles (6.4 km) from the JWPCP. Unfortunately, the projected 3- to 4-year useful life remaining at this facility would render its use for sludge solids disposal short lived. The closest alternate disposal facility would be either the Mission Canyon Landfill or the Puente Hills Landfill, each approximately 30 miles (48 km) from the JWPCP. Certainly, the economics of hauling to either of these facilities would take on a slightly different picture.

Incineration would surely qualify as an appropriate means for reducing the overall tonnage requiring disposal. Considering the volatile content of the sludge solids and assuming that the sludge could be dewatered to a suitable extent, the combustion process would likely be autogenous, i.e. self supporting. If so, then the heat value gained might be conserved for usage elsewhere. The inert ash would perhaps be useful for conditioning the centrate or digested sludge prior to dewatering. Or if such chemicals as lime are necessary for the dewatering process, their recovery might be possible in a recalcining scheme. On the surface, it would appear that sludge incineration had an obvious place in the overall scheme of things at the JWPCP. In view of the air pollution problem existing in Los Angeles County, however, public and regulatory acceptance of such an operation would prove difficult and costly to attain. Besides, the Districts had no desire to augment the air pollution problem for the sake of solving its sludge problem.

In view of the previous, it can readily be seen that the Districts sludge problem was one of sizeable magnitude and complexity and a considerable investment would be required to effect its solution. Moreover, the success of the operation would be dependent on the reliability of the chosen sludge dewatering scheme.

RESEARCH APPROACH AND EXPERIMENTAL SETUP

Preliminary cost assessments were made for several full scale sludge dewatering and disposal schemes. The resulting estimates indicated that, whatever the means, a sizeable amount of money would be required to dewater to the extent desired. This prompted the Districts to decide upon a course of investigating each promising conditioning aid and dewatering equipment on a piloted basis so as to arrive at the most worthwhile economical scheme.

At the JWPCP, full-scale horizontal scroll centrifuges already existed and thus became the logical starting point for the research work. Preliminary observations had indicated that about 30 percent of the suspended material was being removed from digested sludge fed to the dewatering station. Generated cakes had a solids content ranging between 30% and 35% by weight. It was generally felt that this performance could be improved. However, a systematic evaluation of various operational parameters would be necessary in order to verify this and define the limitations involved. Accordingly, preparations were made to isolate one of the centrifuges for test purposes.

In addition to horizontal scroll centrifuges, other types of dewatering equipment which seemed to have a potential application for handling either digested sludge or centrate included basket and disc centrifuges, coil and cloth belt vacuum filters, and pressure filters. Representative equipment was procured from available sources, and mention of product names does not imply endorsement by the Districts or the EPA. A basket and disc centrifuge were acquired from Sharples Centrifuge Company, a Division of Pennwalt Corporation. A coil filter was obtained from Komline Sanderson, Inc. Two cloth belt vacuum filters -- a rotary drum type and a horizontal belt type, called an extractor -- were furnished from Eimco Corporation, a division of Envirotech Corporation; a diaphragm press was also provided by this corporation. A pressure filter was acquired from the Beloit-Passavant Company. A description of each of these units will be provided later in this report.

In conjunction with the above dewatering equipment, four methods of sludge conditioning would be evaluated. These included polymer conditioning, chemical conditioning (lime and/or ferric chloride), heat conditioning and flyash conditioning. Contacts made with various polymer manufacturers revealed that cationic polymers would be most suitable for testing. Accordingly, arrangements were made for purchasing their various recommended products as the needs of the research work dictated. The procuration of lime and ferric chloride for this investigation posed no problem since these products were quite readily available on the open market. Special equipment would be needed, however, if heat and flyash conditioning were to be evaluated.

Contacts were made with manufacturers of heat conditioning equipment regarding an investigation of their respective processes on a pilot plant scale. As a result, the Districts rented a 200 gallon-per-hour (12.6 l/min) Porteous pilot plant.

Two lines of approach were available to the Districts regarding the conditioning of sludge with flyash. Either incinerated ash from an outside facility could be procured for use in this study, or suitable equipment could be made available to the Districts for the generation of its own flyash. The latter approach was chosen since it would provide the Districts with the opportunity of assessing the combustion properties of the various sludge cakes generated from the different dewatering equipment to be tested. Accordingly, incinerator manufacturers were sought out in this regard. As a result, an arrangement was made with BSP Envirotech to furnish a six-tier multiple hearth incinerator for the study.

Considering the large number of products and manufacturing equipment which were to be evaluated at the JWPCP, it was evident that a suitable research facility would be required at which to conduct the work. An area was selected within the confines of the treatment plant and a research site and chemical station were constructed. A detailed description of each of these are presented in the following subsections along with a followup description of each of the pilot plant units tested.

RESEARCH SITE

The area selected for the research work was located adjacent to the existing dewatering station at the JWPCP (see Figure 3). Following grading and placement of a 6-inch (15.2 cm) compacted rock base, an 80-ft by 85-ft (24.4-m by 25.9-m) reinforced concrete slab was formed and poured in place. A sloped, concrete drainage channel of 24-inch (61-cm) width was constructed along one side of the slab. Its purpose was to collect the drainage from the slab area and to serve as an effluent disposal point for the various pilot plant units tested. The drainage channel terminated at a sump. An automatically controlled sump pump was installed to recycle the collected drainage and effluent wastes back into the treatment plant system.

A centrally located electrical panel (Westinghouse model) equipped with starters and breakers of various sizes was installed on the research slab area. This served as the distributing power source for all miscellaneous electrical equipment (pumps, mixers, lights, etc.) as well as the pilot plant units themsleves. The panel, in turn, was supplied power from an existing breaker panel at the JWPCP dewatering station. For nightwork purposes, a large overhead 400-watt floodlight was installed atop a 30-ft (9.2-m) high pole located on one corner of the research site. The area was unroofed and exposed to the weather.

Two 10-ft (3.0-m) diameter, 8-ft (2.4-m) high cylindrical fiberglass tanks (Figure 4), each of 4,700-gal. (17.8-cu m) capacity, were installed adjacent to one another on the research slab. These served as sludge holding reservoirs and were the source of sludge feed material for the pilot plant units tested. Each tank was equipped with tie-down lugs and an externally wall mounted ladder. A 20-inch (51-cm) diameter manway was located on top to provide tank access. The tanks were each furnished with four vertical wall mounted baffles, each located at 90° from one another around the internal periphery. In addition, each tank was equipped with an internally, top-located wash water spray ring for washing of the tanks' walls.

A network of piping was constructed from the existing centrifuge dewatering station to each tank. The arrangement and tie-ins were such that either tank could be filled with any of the following:

FIGURE 3

Joint Water Pollution Control Plant
Sludge dewatering research site

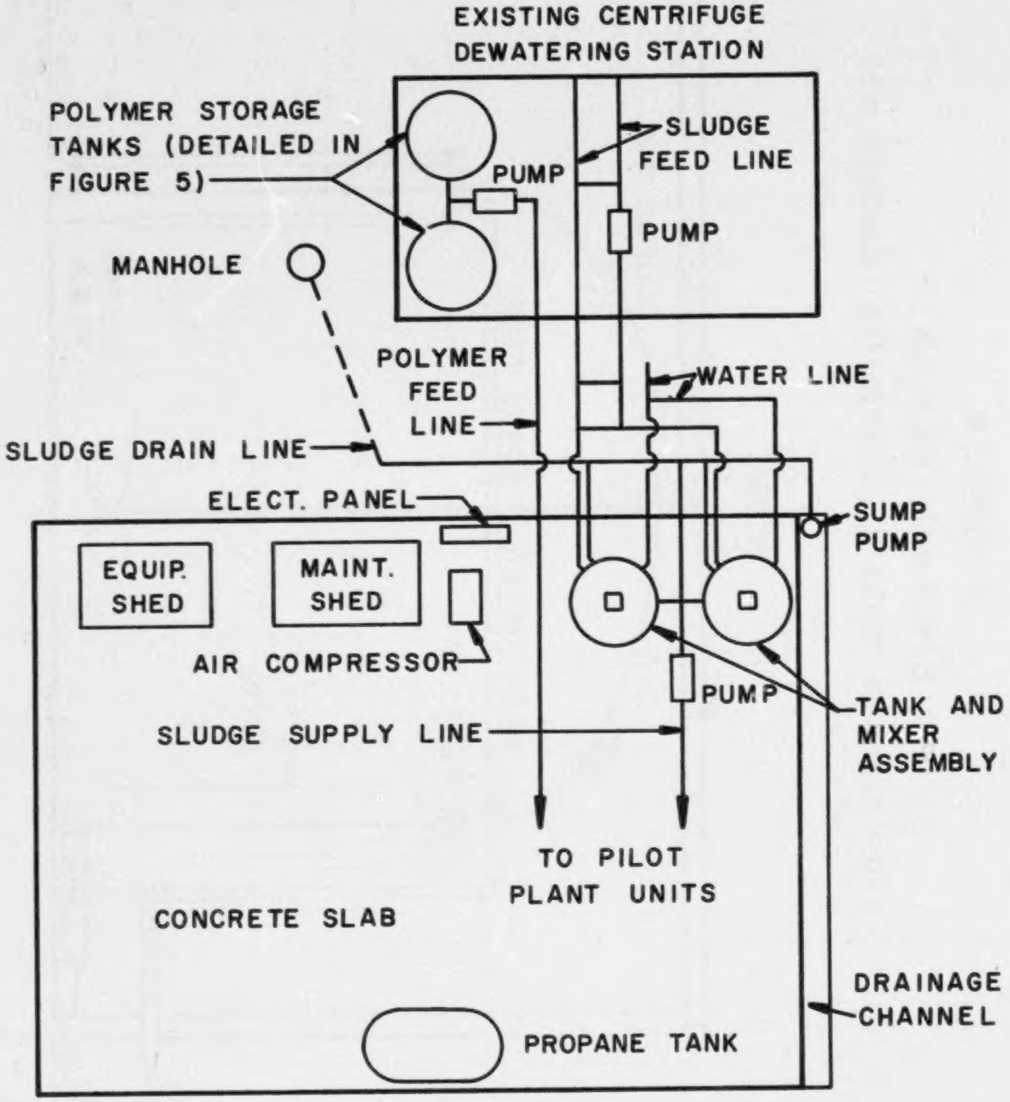
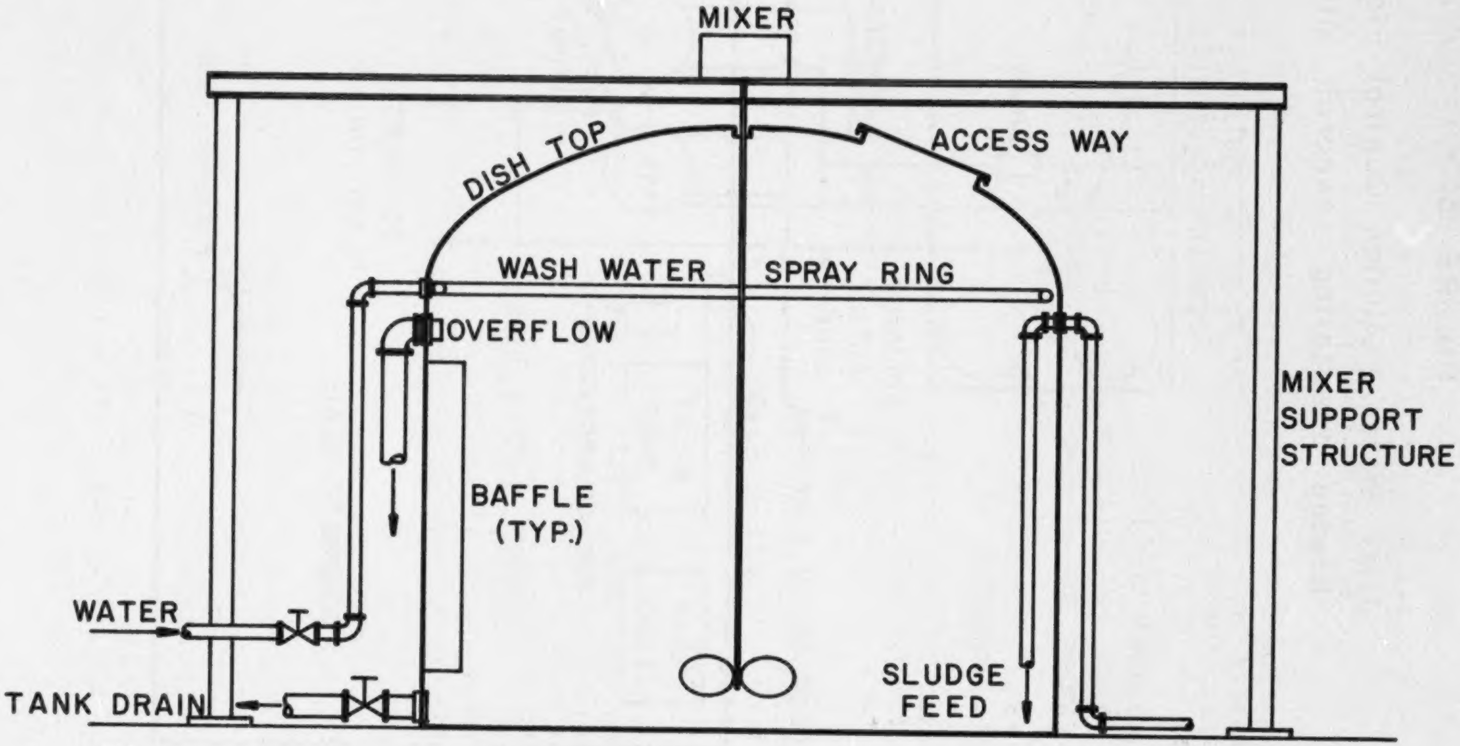


FIGURE 4

Schematic diagram

Sludge storage tanks at dewatering research site



(1) digested sludge fed to the dewatering station,

(2) centrate effluent from the Bird centrifuges,

(3) screened centrate effluent from the vibrating screens.

An overflow drain line was connected at the top of each tank to prevent accidental overflow of the tanks contents during filling. Other miscellaneous pipe connections were arranged for either draining each tank or directing their respective contents (by gravity feed or controlled pumping) to any of the pilot plant units tested. Controlled feeding was accomplished using a variable speed progressive cavity pump (Moyno type, Model 1L4) with capacities ranging from 30 to 78 gpm (1.9 to 4.9 l/sec). The overflow and drainage from each tank were conduited back into the treatment plant system.

In order to keep the contents of each tank in a somewhat homogeneous state for distribution to each pilot plant, each tank was provided with a slow speed (84 rpm), 2-hp (1.5-kw) mixer (Lightnin Model 71-Q-2). Each mixer was equipped with a 37-inch (94-cm) diameter turbine type propellor mounted on the end of a 2-inch (5.1-cm) diameter, 114-inch (290-cm) long shaft. The mixer assembly was supported over each tank by a spanned steel frame structure fabricated by plant personnel.

A 300-gal. (1.1-cu m) propane tank was installed adjacent to the slab area. This served as a reservoir for the necessary fuel required for operating some of the pilot plant units. A compressor and air storage tank was provided to supply compressed air as the needs dictated. Also, two portable buildings were furnished to house the operating and maintenance research personnel and to provide storage for tools, miscellaneous piping, valves and other appurtenances.

CHEMICAL STATION

A small area was selected between the research slab area and the existing centrifuge dewatering facility for the construction of a chemical mixing station (refer to Figure 3 for location). Here, polymer solutions could be batched into desired solutions and control fed to any of the pilot plant units on the slab area or to one of the 36-in. x 96-in. (91.4-cm x 243.8-cm) horizontal scroll centrifuges at the dewatering station that was isolated for test purposes. The station consisted of 2 cylindrical fiberglass tanks, each of 1,400-gal. (5,300-1) capacity (Figure 5). Each was equipped with an eductor for injecting dry polymers into solution and with a mixer for effecting solution homogeneity. The mixers were 2-horsepower (1.5-kw) direct drive units (Lightnin Model ND-4A) operable at a constant speed of 1,750 rpm. Located at the middle and end of each mixer shaft was a 12-inch (30.5-cm) diameter, tri-bladed mixing propellor. Two progressive cavity Moyno pumps (Model 1L3) were installed at the station for controlled delivery of batch polymer solutions to the processing units. One of the pumps was a fixed speed unit whereas the other was of variable speed. Between the two, batched polymer feedrates from 0.6 to 13.6 gpm (0.04 to 0.86 l/sec.) were possible.

Located at the discharge end of each pump was another eductor connected to a meterable water supply. This enabled the pumped polymer solution passing within the eductor to be further diluted to any desired degree. Additional equipment, such as rotameters, water meters, pressure reducing valves, and miscellaneous globe and gate valves were incorporated into the piping network of the station as was necessary for controlling and metering specific quantities and flow rates of water.

PORTEOUS PROCESS AND ACCESSORY DEWATERING EQUIPMENT

The major components making up the 200-gal./hr (12.6-l/min) pilot plant unit used in this investigation consisted of the following individual pieces of equipment (see Figure 6):

(1) A Moyno mazorator (grinder),

(2) A high pressure progressive cavity pump (Moyno type),

(3) Two heat exchangers -- one for preheating and one for cooling,

(4) A 240-gal (908-l) reactor pressure vessel,

(5) A steam generating boiler unit equipped with a boiler blowdown system,

(6) Miscellaneous pumps and expansion tanks for

FIGURE 5

Schematic flow diagram
Chemical station

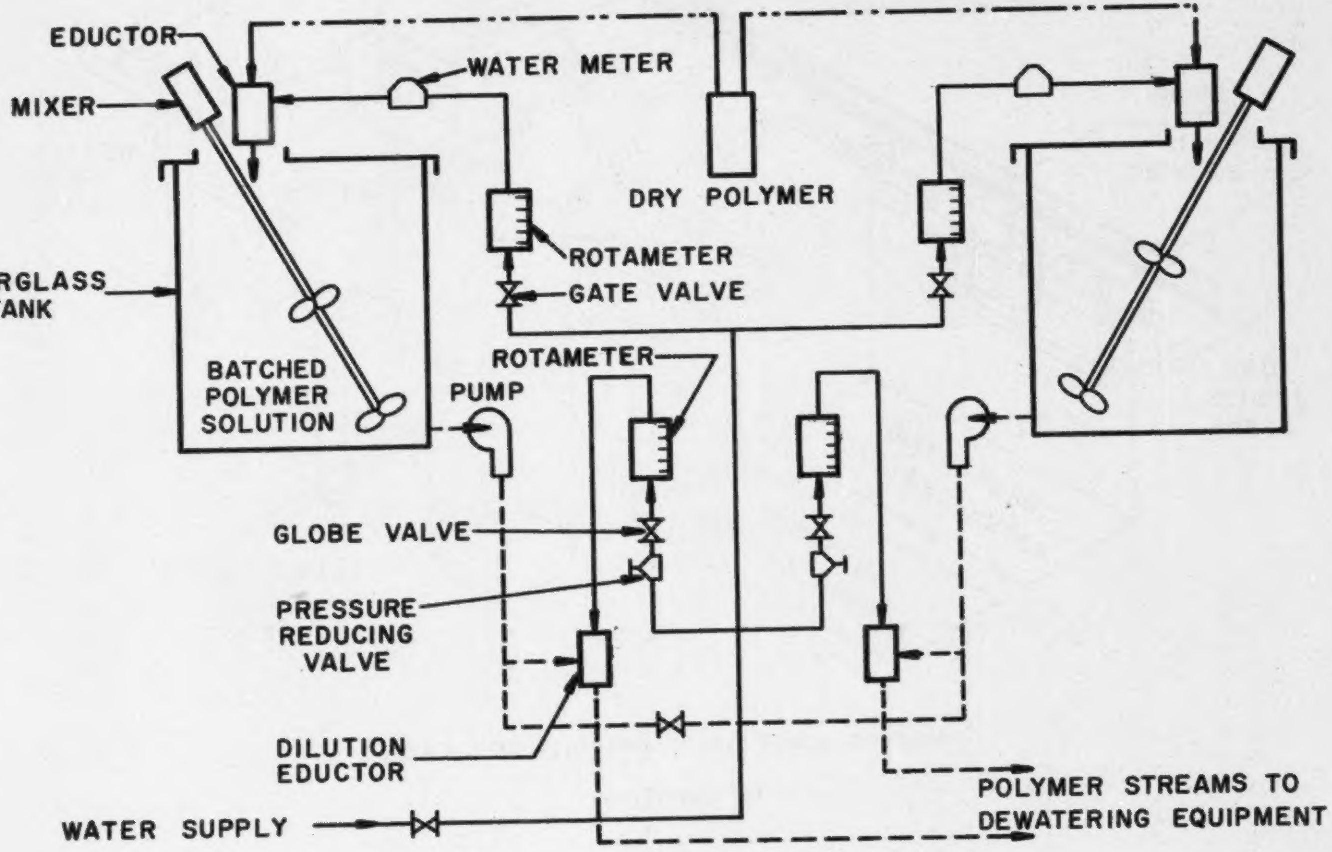
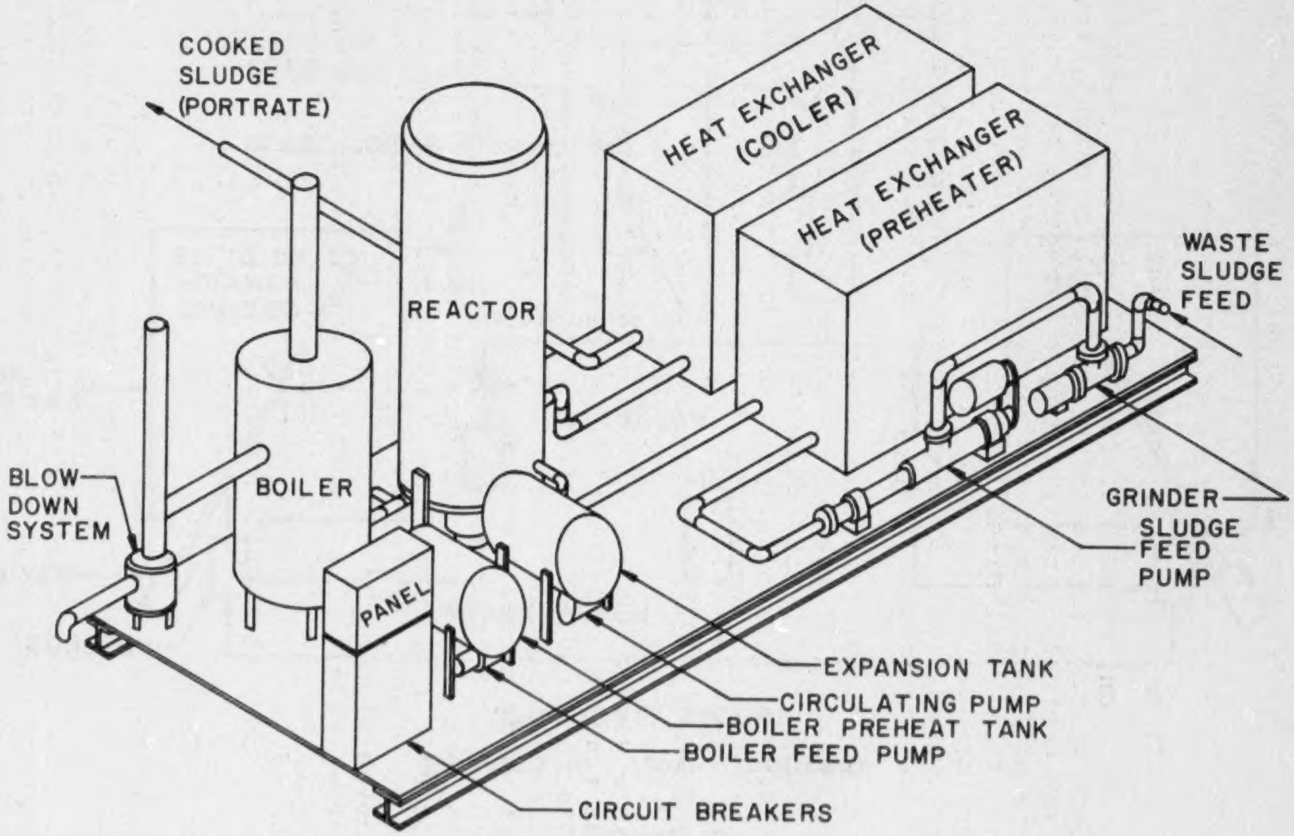


FIGURE 6

Heat conditioning pilot plant assembly



(a) the heat exchanger circulating water system and

(b) boiler feed water system,

(7) An electrical control panel.

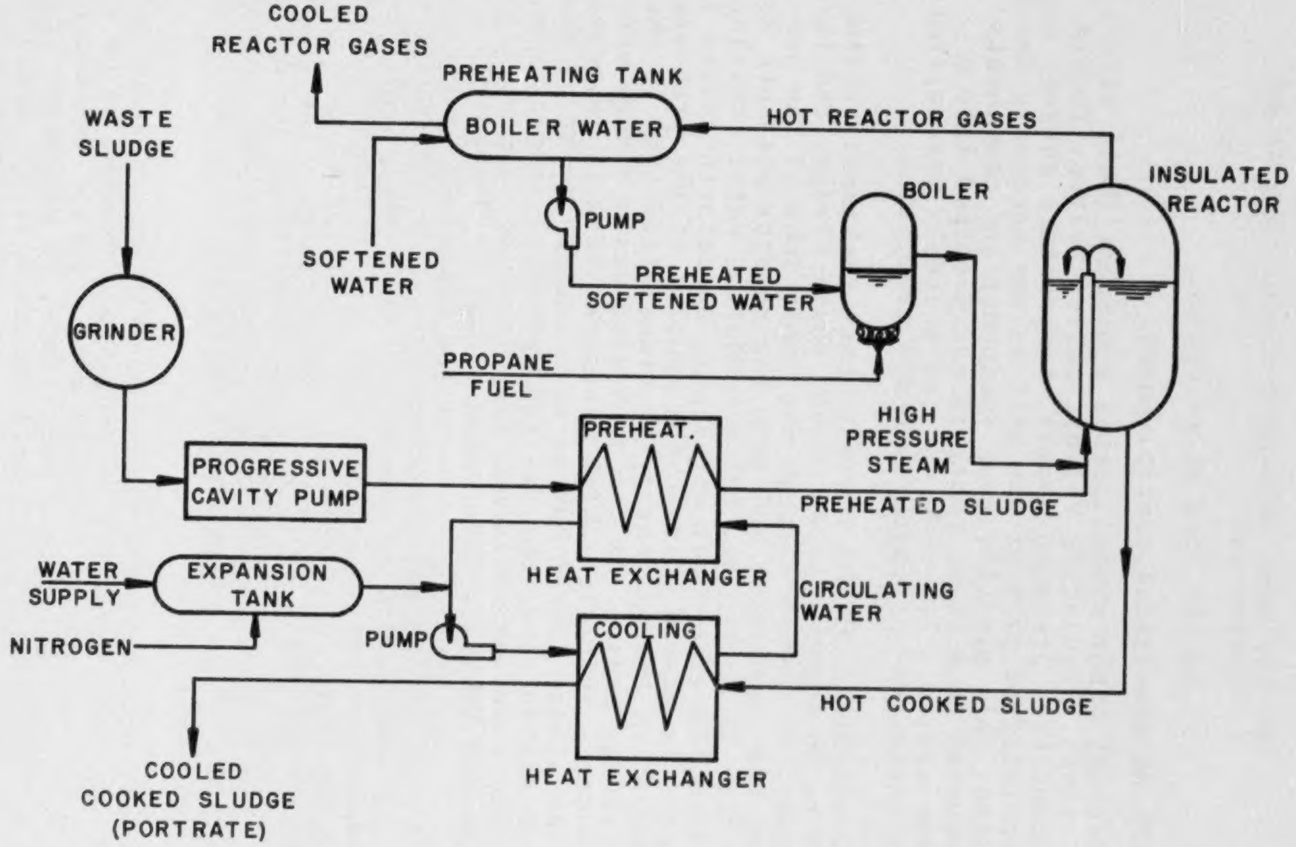
In addition, other miscellaneous equipment (ball valves, check valves, regulating valves, relief valves, liquid level controls, pressure gauges, temperature gauges, etc.) were an integral part of the unit as was necessary for its operation. All miscellaneous equipment and components were mounted on a steel platform and prepiped into a workable system. The skid mounted assembly was delivered to the Districts' research site for evaluation.

A flow schematic of the Porteous heat treatment system is presented in Figure 7. As noted, waste sludge, fed through a grinder, is pumped through the inner tube of the preheating heat exchanger and into the reactor pressure vessel. While this is happening, hot circulating water crossing over from the other heat exchanger, henceforth called the "cooler", is passed through the annulus of the preheater whereupon its thermal energy is transferred over to the waste sludge phase. As the preheated waste sludge enters the reactor, sufficient high pressure steam is injected into the sludge flowstream as is necessary to bring the reactor contents to some desired operating temperature. Following a preset residence time (cooking time within the reactor vessel), the cooked sludge is discharged under pressure into the inner tube of the deheating heat exchanger. Cooled circulating water crosses over from the cooler wherein it becomes heated by thermal energy transferred from the cooked sludge phase. Once heated, the exiting hot circulating water is redirected to the preheater to give up its energy to the newly introduced waste sludge. The final cooled, cooked sludge exiting the deheater is the desired heat conditioned product which is available for further processing. This product will hereinafter be referred to as "portrate".

Accessory equipment was furnished with the Porteous pilot plant unit enabling further processing studies to be carried out on the portrate. Included were a picket thickening tank, a horizontal scroll centrifuge, an extractor (top loading, horizontal cloth belt vacuum filter), and a diaphragm press. The following is a brief description of each of these.

FIGURE 7

Schematic flow diagram
Heat conditioning pilot plant



(1) Picket Thickening Decant Tank -- A 390-gallon (1476-liter) cylindrical tank with a conical shaped bottom. Unit was equipped with a rotary driven bottom sweeper with attached vertical pickets.

(2) Horizontal Scroll Centrifuge -- A Sharples P-600 unit equipped with fixed speed bowl drive and variable speed scroll drive motors. A storage feed tank and a progressive cavity feed pump accompanied the unit.

(3) Extractor -- A 12-foot (3.7-meter) long Eimco horizontal top loading vacuum filter equipped with variable speed driven cloth belts having a one-foot (0.3-m) wide face.

(4) Diaphragm Press -- An Eimco experimental unit consisting of a moveable cloth belt within a hydraulically operated press plate. An air operated high pressure feed pump accompanied the unit.

Other pilot plant equipment were also assessed as to their portrate dewatering capabilities. A description of these, however, will be presented in more detail in subsequent subsections.

Installation of feed, drain, water, compressed air and reactor vent lines was made between the Porteous pilot plant, the various accessory equipment, and the existing research facilities. Installment of a high pressure gas line served to connect the propane tank to the boiler of the pilot plant unit. Minimization of boiler scaling was accomplished with the hook-up of a Culligan soft water unit to the boiler feedwater system. A radioactive source and detectors were installed on the reactor as an integral part of the automatic level control system. A high pressure nitrogen source was tied into the expansion tank of the circulating water system. This enabled controlled pressurization of the circulating water within the heat exchangers.

HORIZONTAL SCROLL CENTRIFUGE

Horizontal scroll centrifuges generally fall into three basic shapes, namely conical, cylindrical and cylindrical-conical. Both the Sharples P-600 decanter and Bird centrifuge used in this investigation were of the cylindrical-conical type. Both were capable of dewatering on a continuous basis with countercurrent discharge of the fractionated effluents.

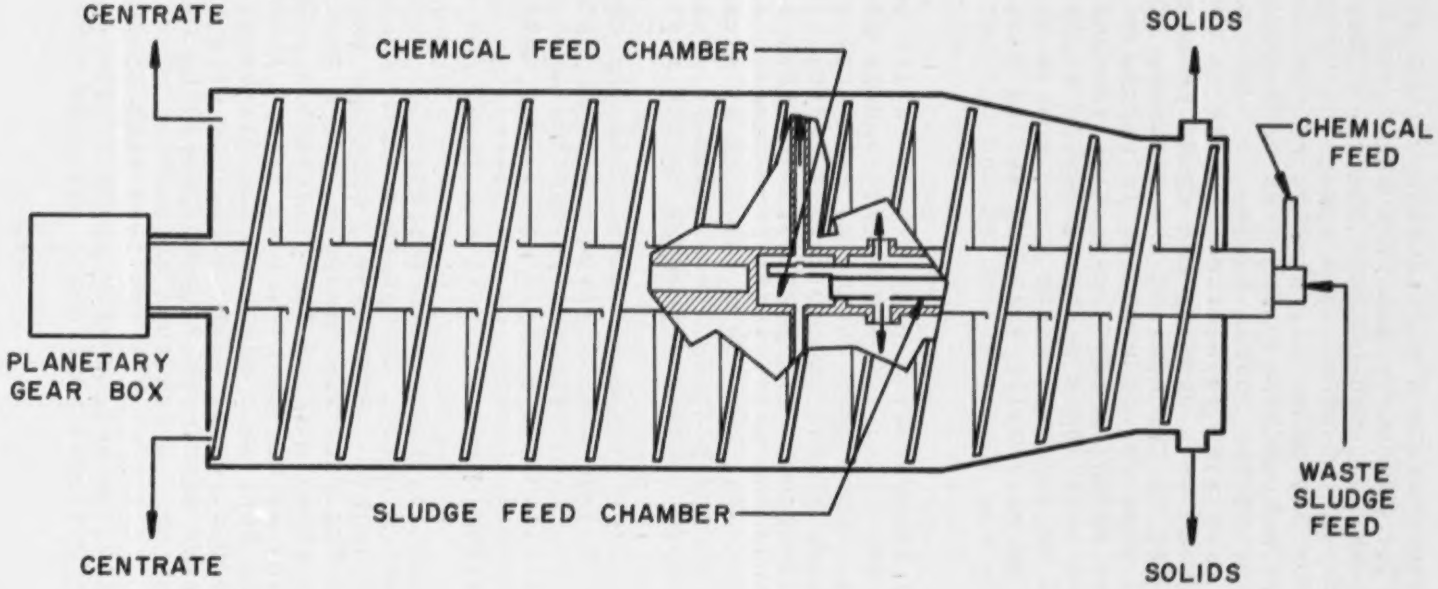
A typical section of one of these centrifuges is presented in Figure 8. Basically the unit consists of two horizontally rotating elements. The outer rotating element is a solid cylindrical shell joined at one end to a section of a truncated conical shell. The ends of this bowl assembly are supported by a head plate with an integral trunnion. The inner rotating element resides within the bowl and consists of a smaller diametered cylindrical hub and hollow shaft assembly with an attached blade formed axially around the outer wall to produce a helical screw. During operation, this screw assembly is driven by a planetary gear reduction unit at a somewhat slower speed than the bowl. The net effect is a screw conveyor inside of a revolving bowl. The entire rotating assembly is mounted on a frame to which is bolted a semi-cylindrical welded steel top cover.

The sludge slurry is fed into the machine through a hollow stationary pipe extending part way into the hollow shaft of the screw conveyor or scroll. This feed material is deposited within one of two compartmentalized chambers within the scroll. Multiple ports situated around the outer wall of this rotating chamber allow passage of the sludge into the outer bowl region. Because of the difference in rotational speeds, sludge entering the bowl region is distributed uniformly around the bowl wall. The other chamber within the scroll is generally used for receiving a separately fed chemical stream and independently distributing or injecting it into that already present within the bowl region; when not in use, the diffusion ports of this chamber are usually sealed off to prevent backflow intrusion of unwanted material. The distribution of sludge against the bowl wall results in the formation of a rotating annular pool whose depth is regulated by adjustable overflow weirs situated at the large diameter end of the bowl. As the liquid moves towards these weirs, the suspended solids centrifugally gravitate or migrate through the pool towards the bowl wall. Thus, the liquid overflowing the weir (centrate) has a reduced suspended solids load. The solids which are deposited against the bowl surface are scrolled back through the moving liquid pool and up the conical beach whereupon they eventually break through the pool's liquid surface and undergo drainage prior to discharge through exit ports. The dewatered sludge cake and centrate are discharged into separate external hoppers mounted beneath the machine.

The Bird centrifuge selected for evaluation was one which operated at a constant bowl speed of 1300 rpm and thereby

FIGURE 8

Cross-section of a countercurrent flow horizontal scroll centrifuge



produced 900 gravities at the wall of the cylindrical section. The planetary gear reduction was such that the differential speed between the bowl and scroll remained constant at about 15.3 rpm. The machine was first removed from its pedestal, dismantled, reconditioned and modified as was necessary for test purposes. This included refacing the scroll blades to their original dimensions, providing reinforced support to the cover at the cake discharge end, opening the chemical chamber injection ports leading to the bowl of the machine, installing a multi-tubed feed pipe for independent injection of both sludge and polymer solution into respective chambers within the scroll, and adapting a skimming device at the centrate discharge end of the bowl which would enable the pool depth within to be externally adjusted during machine operation. The machine was then reassembled and put back on its pedestal.

A variable speed driven progressive cavity pump (Moyno type) was installed for controlled sludge feeding to the centrifuge. The speed range was such that sludge feedrates ranging from 100-450 gpm (6.3-28.4 l/sec) were possible. The installation of the pump was such that its suction side was tied into the main sludge line feeding all six centrifuges at the station. Thus, as long as sludge was being delivered to the station, some would be available (under pressure) for controlled pumping to the test centrifuge.

Plastic (PVC) pipe was installed from the chemical station to the centrifuge installation. Tie-ins were such that chemicals could be optionally injected into either the suction or discharge side of the sludge feed pump or separately into the bowl of the centrifuge itself. With this work completed, the unit was ready for evaluation.

The experimental setup with the Sharples P-600 decanter was somewhat similar, though on a much smaller scale. The centrifuge itself operated at a constant bowl speed of 5000 rpm. The unit was equipped with a variable speed back drive which enabled the differential speed between the bowl and the scroll to be varied from 7 to 44 rpm. Overlapping the bowl weir plate on the discharge end of the bowl was a second circular plate with four sets of punched holes located along spiral arms radiating outward from the plate's center. Rotational adjustment of this overlapping plate enabled any one of the four sets of holes to be aligned with the larger weir holes of the inner fixed plate. Thus, four optional pool depth settings were available;

partial dismantlement of the machine, however, was necessary to change from one pool depth setting to another. The feed pipe was multitubed for independent feeding of sludge and optional chemicals into the bowl. Variable speed driven Moyno pumps were provided for metering both the sludge and chemical feedrates. The respective pump sizes and speed variations were such that sludge feedrates ranging from 1.0 to 5.8 gpm (3.8 to 21.9 l/min) and chemical feedrates ranging from 0.02 to 0.18 gpm (0.08 to 0.68 l/min) were possible. Preceding each pump was a small reservoir tank. The sludge tank was equipped with feed, drain and overflow lines; the chemical tank was furnished with an eductor, a mixer, and a meterable water supply.

BASKET CENTRIFUGE

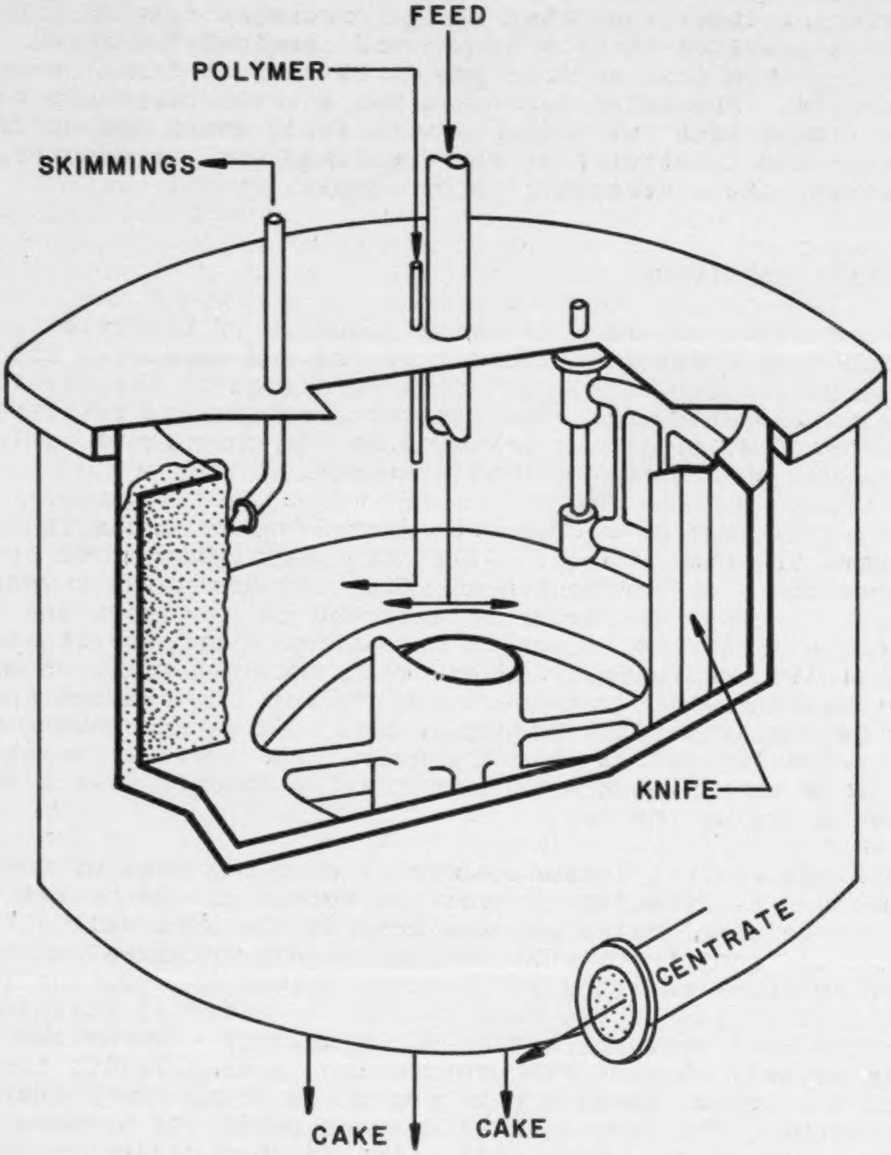
Basket centrifugation of waste slurries is basically a batch type operation. Sludge is fed and dewatered simultaneously along with continuous discharge of the clarified effluent (centrate). The dewatered solids are retained for later discharge at a time when the throughput of feed material has been temporarily ceased.

A typical section of a basket centrifuge is shown in Figure 9. Characteristically, the unit consists of an imperforate cylindrical bowl which rotates about a vertical axis. An annular baffle is attached to the upper end of the bowl, thereby forming a weir whose crest is situated some distance radially inward from the bowl wall. A similar arrangement exists at the bottom of the bowl except that it is much more a floor structure and does extend inwardly to a greater extent than the weir. The overall configuration of this assembly is such that it appears like a basket with a lip on the top.

Feed material is introduced at or near the axis of rotation and is directed towards the bottom of the basket thereat to be accelerated outward towards the bowl wall. A separate though somewhat similar feed arrangement exists for optional addition of chemical solutions. During the initial stages of the feed cycle, the material introduced to the bowl near the bottom flows upwards towards the top lip or weir whereat its progression is temporarily halted and a trapped, annular pool begins to form. As feeding continues, the trapped pool deepens until its surface reaches the crest of the upper weir. Liquid then begins to overflow the weir signifying the end of the fill cycle and the

FIGURE 9

Schematic diagram of a basket centrifuge



beginning of an equilibrium feed-discharge phase of operation.

In the equilibrium phase, the trapped annular pool region between the bowl wall and the weir crest becomes a quiescent zone for the gravitational movement of suspended solids. Overlying this is a thin moving liquid layer travelling upwards towards the discharge end. Suspended material, while within this moving layer, migrates towards the quiescent zone for continued settling. Hence, a discharged overflow or centrate results having a reduced suspended solids load. During the equilibrium phase, solids accumulating within the quiescent zone build up and compact against the bowl wall. This continues until the capacity of that region for solids accumulation becomes exhausted. At this point, the rejected solids are carried out with the overflow causing centrate clarity to diminish. This signifies the end of the feed cycle. Feed to the unit is then halted until the dewatered solids are removed from the bowl.

The accumulative buildup of solids during the feed cycle is such that those solids residing closest to the bowl wall are more compact; thus, the solids cake in that location contains less moisture per unit of occupied volume and is therefore drier. Conversely, solids residing more inward and away from the wall are progressively less compact making the collected cake in that region correspondingly wetter. The progression is such that at the crest of the overflow weir lies a semidewatered paste and a thin layer of unclarified liquid. This latter material is removed to any desired depth by means of a skimmer. The skimmed contents are discharged through a hose. This is accomplished while the centrifuge is running at full speed. The skimmer is then retracted and the bowl is decelerated to a very slow speed whereupon the remaining drier cake is peeled from the wall with a large bladed knife. The knifed contents fall through open quadrants at the bottom of the basket for conveyance to a discharge point. Upon retraction of the knife, the solids discharge cycle is completed. The bowl is reaccelerated to full speed and the feed cycle reinitiated.

Two basket centrifuges were utilized in the Districts' dewatering study. The first was a 30-inch (76-cm) diameter machine driven by an electric motor at a constant speed of 1750 rpm. This provided 1300 gravities at the wall of the bowl. The 4-inch (10.2 cm) weir lip in conjunction with the basket's length provided a 6-cu ft (0.17-cu m) annular reservoir for solids accumulation. The basket of this unit was not equipped with an open bottom for solids discharge. Consequently, all accumulated cake solids were removed by skimming. This latter aspect proved troublesome for this work, and so a second machine was brought in to take its place. This second unit was equipped with a 40-inch (102-cm) diameter bowl and was hydraulically driven to provide an upper speed of 1500 rpm (1300 gravities at the bowl face) during feeding and skimming. Provisions were such that the solids (or a portion thereof) could be knifed out upon hydraulic deceleration to a lower bowl speed (approximately 100 rpm). The 6-inch (15.2 cm) weir lip in conjunction with the basket length provided a 9-cu ft (0.25-cu m) annular reservoir for solids accumulation. The unit was completely furnished with the necessary controls which enabled full automation of the entire operation.

Both of the above discussed centrifuges were evaluated in the second stage mode as to their capabilities for dewatering centrate from the existing solid bowl centrifuge station. A variable speed progressive cavity feed pump (Moyno type) was used to meter the feeding of first stage centrate to each unit tested. Speed ranges were such that feedrates ranging from 10-70 gpm (0.60-4.41 l/sec) were possible.

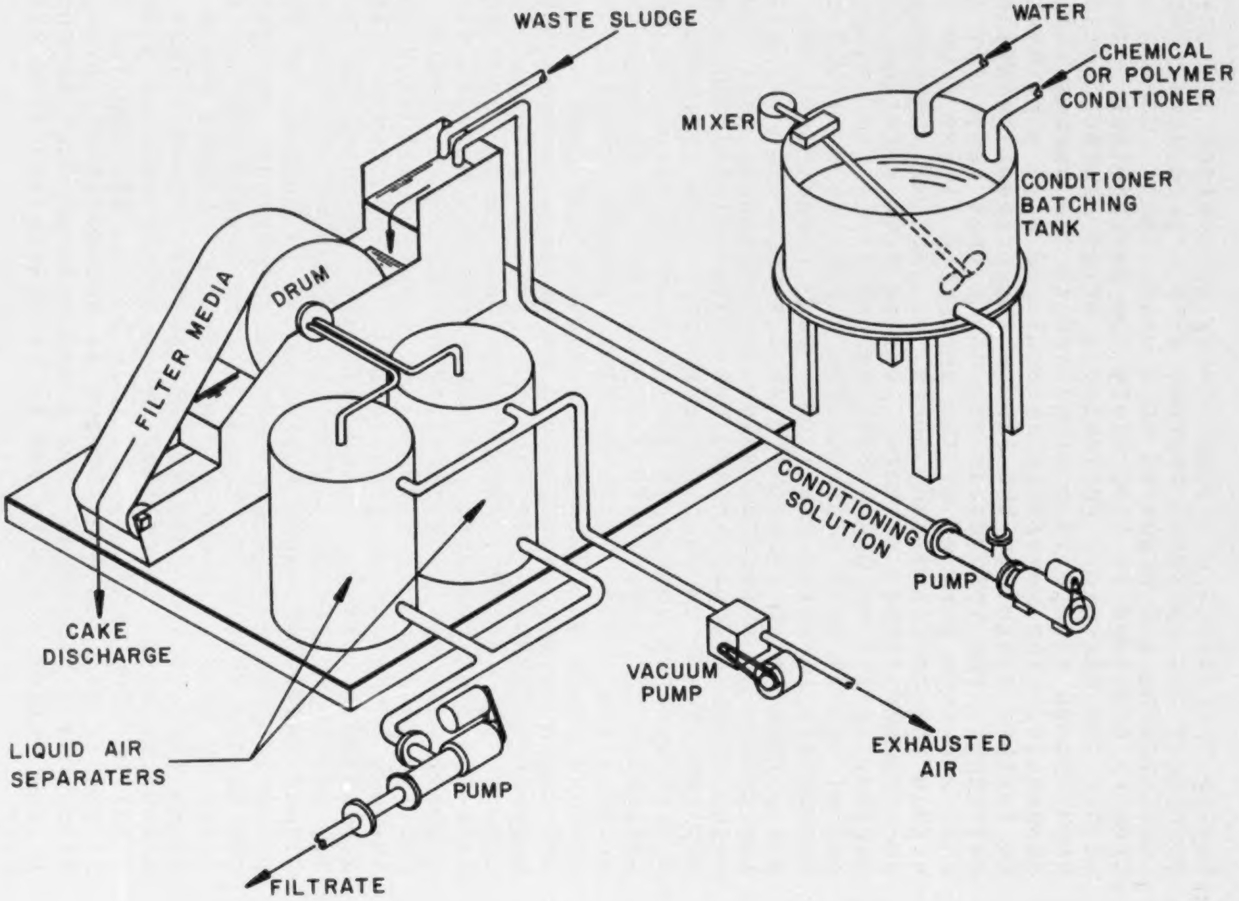
ROTARY DRUM VACUUM FILTER

Two types of rotary drum vacuum filters were evaluated as part of the Districts research work, namely an Eimco cloth belt filter and a Komline-Sanderson coil filter. Both were pilot units of the same size and basic configuration. Both were mounted on a steel platform along with other miscellaneous components (electrical panel, drive motors, vacuum and filtrate pumps, liquid-air separators, etc.) necessary for functional operation and testing. Figure 10 shows the basic layout of the skid-mounted assembly of each.

Situated near one end of each filter unit is a variable speed driven, 3-foot (0.9-m) diameter cylindrical drum having a one-foot (0.3-m) wide face. Located at the opposite end is a roller assembly, the rotation of which axially parallels that of the drum. Looped peripherally around the drum and roller assembly is the belted filter media. In the case of the coil filter, this consisted of a two-layered mat of stainless steel, 0.41-inch (10.4-mm) diameter helically coiled springs layed in corduroy fashion. The

FIGURE 10

Rotary drum vacuum filter pilot plant assembly



media for the Eimco unit consisted of a one-foot (0.3-m) wide woven cloth belt of synthetic material (nylon or polypropylene).

During operation, a sludge slurry is control fed to a reservoir for optional contact with a separately fed conditioning aid prepared in a batch tank. Gentle agitation is provided to flocculate the particulate matter within the mixture. Following a brief contact period, the conditioned sludge is control fed to the vacuum filter reservoir. The reservoir is equipped with a bottom agitator to further coagulate the sludge and prevent localized settling. The volumetric region of this reservoir is such that a bottom portion of the supported filter drum lies within its confines and, hence, is partially submerged in the preconditioned mixture. During drum rotation, the overlaying filter media belt is endlessly fed into and out of the flocced slurry. The filter drum itself is internally compartmentalized. Each compartment has internal piping which terminates at a trunnion on one side of the drum. An automatic valve is located at this trunnion which enables separate and controlled distribution of applied vacuum to each compartment. As a compartment of a drum becomes submerged in the slurry, vacuum is automatically applied, thereby drawing sludge through the overlying filter media into the drum chamber. During the initial stage of submergence, sludge particles larger than the media pores are impeded from passage. They, therefore, began to accumulate on the media surface into a formed cake which, in turn, impedes the passage of finer solids into the drum chamber. As submergence continues for each compartment, solids accumulate on the filter media. Only the liquid and very fine solids fraction actually pass through the pores of this formed cake boundary; this clarified material, called filtrate, is continually carried out of the compartment with the exhausted air into air-liquid separator tanks wherefrom it is pumped for further processing or discharge. As the compartment emerges from the filter reservoir, the resulting formed cake is further dried by mass transfer of the retained liquid phase to air drawn through the cake by the applied vacuum. This continues up until the filter media breaks contact with the rotating drum surface. At this point, the applied vacuum is ceased and the compartment is automatically brought to atmospheric pressure. The dried cake product is conveyed to the roller assembly end to be discharged from the media belt.

In the coil filter, the two layers of springs travel over different rollers (one in front of the other) and, hence, separate from each other. Dried cake is thus lifted from the lower layer and discharged from the upper layer by means of a tine bar. After passing over the discharge rollers, the coil springs are flexed in two different directions while being spray washed. This insures that a constantly clean filter media is being applied to the drum surface at the start of the cake formation cycle. In the cloth belt unit, the filter media travels, first, over a flex bar and then over a discharge roller having an opposingly wound helical ridge along each half of its length. The bar and roller serve to shear and, hence, break the sheet of dried cake away from the cloth media enabling it to discharge freely. The cloth media is then spray washed prior to its return to the filter drum for resubmergence into the conditioned sludge slurry within the filter reservoir.

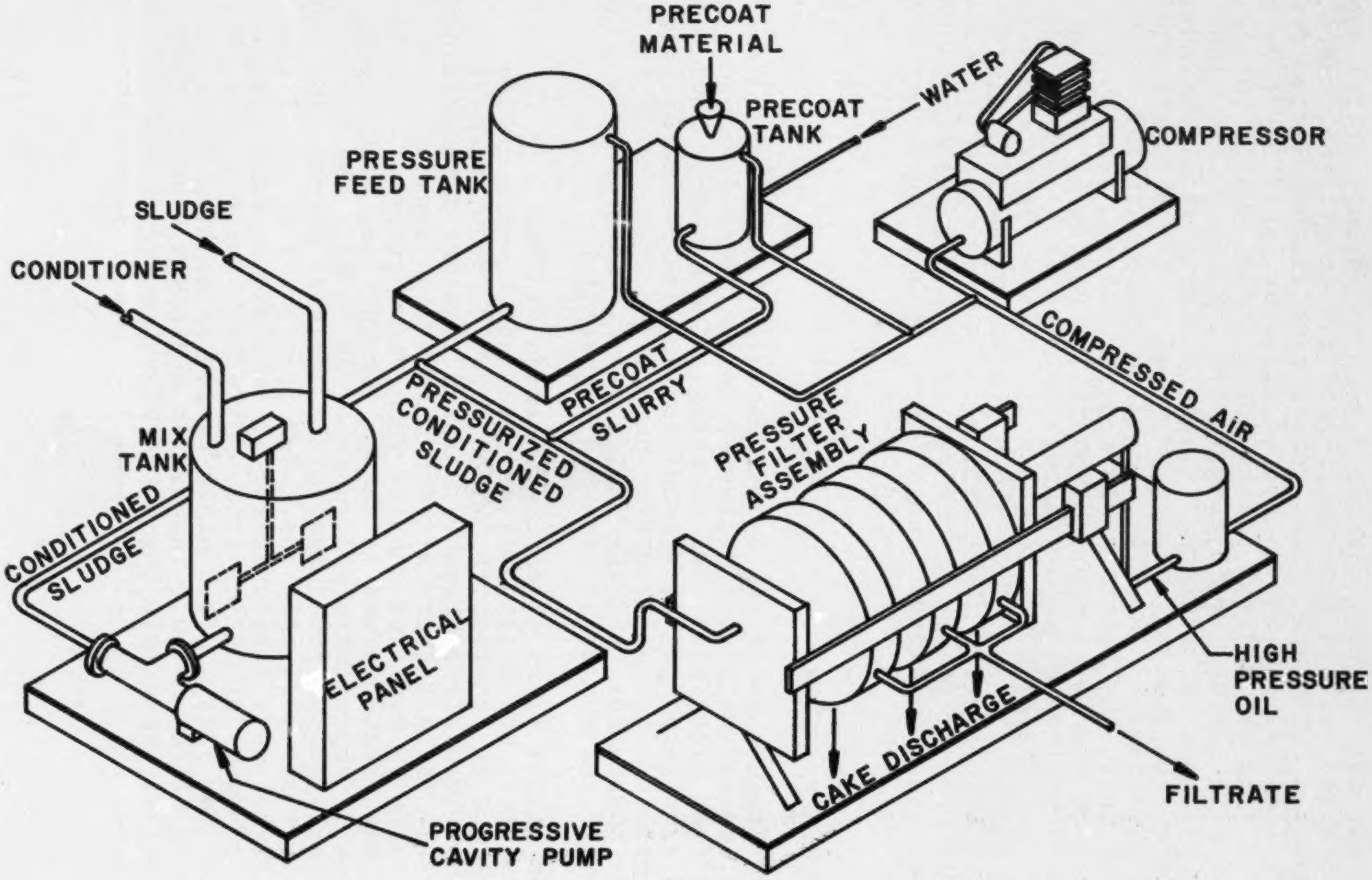
PRESSURE FILTER

The components of the Beloit-Passavant pilot pressure filter assembly were delivered to the JWPCP research site on four steel platforms or skids. The assembly included an electrical panel, a conditioning tank (equipped with a paddle mixer and transfer pump), two pressure tanks, an air compressor, and the filter press. An operational layout of the system is shown in Figure 11.

The filter press assembly consisted of four 2-ft (61-cm) diameter, moveable concave plates which, when butted against one another, provided three 0.38-cu ft (0.01-cu m) compartmentalized chambers linked together through a central port. The periphery of each chamber was sealable from the outside by means of annular rubberized gaskets. The face of each plate served as the filter surface, each having an area of approximately 3 sq ft (0.28 sq m). The interior plates each provided two filter surfaces whereas the end plates provided only one. Hence, a total of six filter surfaces were available which, as a whole, furnished 18 sq ft (1.68 sq m) of filter area. Wire mesh screens were fitted onto the face of each plate to act as backing for an overlayed filter media. The filter media was a woven cloth of synthetic material, the edges of which were caulked into an annular recessed notch around the face of each plate.

FIGURE II

Pressure filter pilot plant assembly



Pressure filtration is a batch type of operation. Sludge is fed to the conditioning tank and is mixed with added conditioning agents (lime, ferric chloride, polymer, ash, etc.). Meanwhile, the filter press plates are closed by means of a hydraulic ram actuated by compressed air. A precoating mixture (diatomaceous earth or flyash, etc. slurried with water) is batched in a small pressure vessel called the precoat tank and then pressure fed at a very high rate into the filter press. The net effect is that the filter media within becomes coated with a very thin layer of the precoat material. Therein, this material will serve to obviate premature blinding of the filter media during sludge feeding and provide readily parting planes between the cloth and later discharged cakes from each chamber. Upon completion of the precoat cycle, the conditioned sludge is pumped from the conditioning tank to a second pressure vessel called the pressure feed tank. The tank and contents are then isolated and pressurized to about 30 psig (2.1 kg/sq cm). Following this, the feed cycle to the filter press is initiated.

Pressurized conditioned sludge enters the filter through a center feed port and distributes itself uniformly through all four chambers. Solid particles deposit against the precoated filter media, while the bulk of the liquid phase and a very small portion of the suspended fines pass through and follow a septum to outlet ports in each plate. The liquid exiting these ports is the filtrate product. As the feed cycle progresses, the retained solids compress and accumulate within each chamber and, in doing so, impart increased resistance to the porous flowthrough movement of the liquid phase. To overcome this, pressure to the feed tank and, hence, to the pressure fed conditioned sludge is increased gradually to a maximum of 220 psig (15.5 kg/sq cm). With the passage of time solids buildup reaches a desired maximum, thus signifying the end of the feed cycle. Feed to the press unit is stopped and all systems undergo depressurization. Oil flow reversal initiates retraction of the pressure filter's hydraulic ram. One by one, the butted filter plates are pulled apart. As each plate separates from the stack, the accumulated filter cake (from the opened chamber in between) shears from the filter surfaces and gravity discharges. Upon removal of all compartmentalized cakes, the plates are washed while preparations are made for the next batch run.

INCINERATOR

The major components making up the pilot incineration plant used in this investigation consisted of the following pieces of equipment (see Figure 12).

(1) A six-tier multiple hearth incinerator.

(2) Two screw conveyors--one for feeding dewatered sludge into the furnace and one for discharging ash residue.

(3) Rabble arm and drive mechanism.

(4) Combustion air blower.

(5) Stack gas scrubber.

(6) Draft induction fan.

(7) Oxygen sampling apparatus.

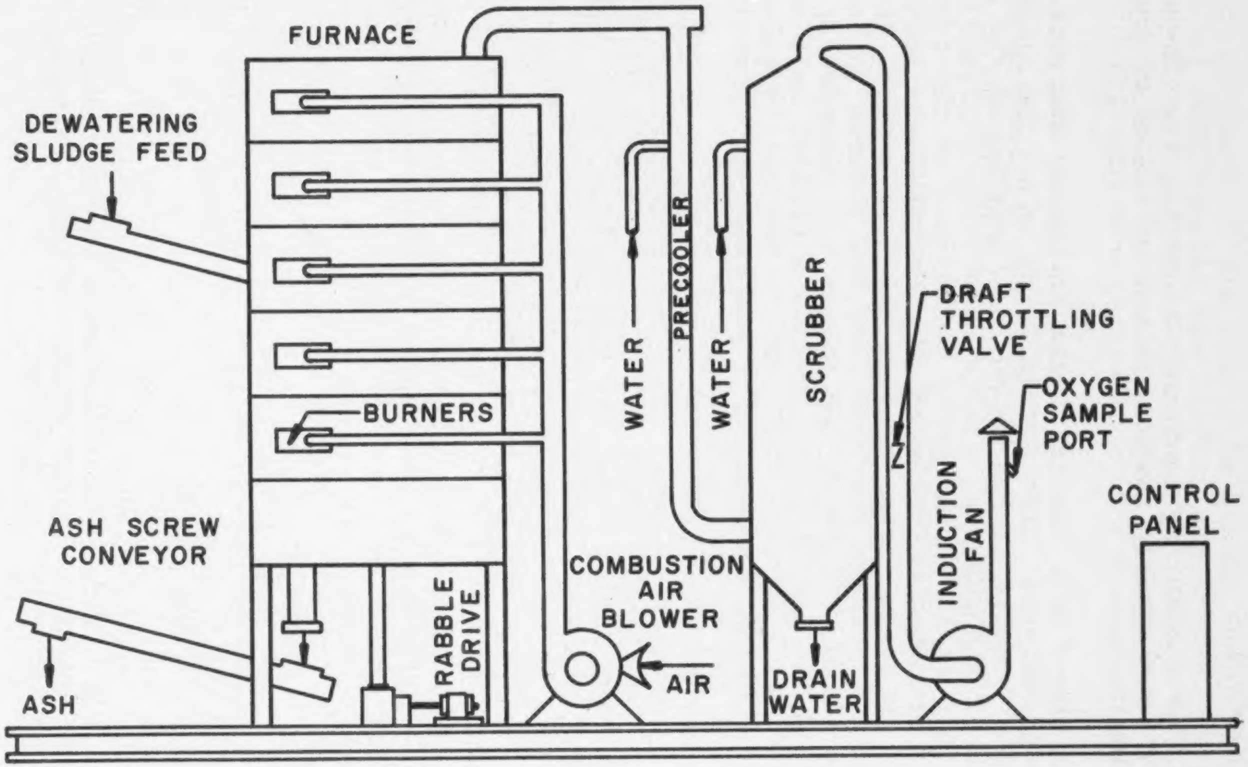
(8) Electrical control panel.

In addition, other miscellaneous equipment (pressure and automatic regulating valves, flow meters, burners, temperature and pressure sensing devices, chart recorders, etc.) were an integral part of the assembly as was necessary for its operation. All miscellaneous equipment and components were mounted on a steel platform and properly connected into a functional system. The skid mounted assembly was delivered to the JWPCP research site for trial combustion of various dewatered sludge cakes and, hence, generation of a flyash conditioning product.

The six-tier multiple hearth furnace was a 30-in. (76-cm) diameter unit having 16 sq ft (1.5 sq m) of hearth area. Hearths No. 1 thru No. 5 were equipped with individual burners and thermocouple sensors. Hearth No. 6 was rigged for pressure sensing. A combustion air blower furnished the air to operate each propane fueled burner. Air delivery to each burner was automatically controlled by throttling valves in accordance with the intensity of burner operation required to maintain a desired hearth temperature. Fuel flow to each burner was, in turn, automatically regulated by the amount of air flow being administered. The gases of combustion were drawn from the furnace by means of an induction fan. The rate of withdrawal of these gases was automatically controlled by a draft throttling valve in accordance with maintaining both a desired negative pressure on the lowest Hearth No. 6 and

FIGURE 12

Skid mounted pilot plant incinerator assembly



a sufficient amount of excess air (oxygen) in the stack gases. Excess air control was accomplished by the feedback of monitoring equipment analyzing the oxygen content of a continuously sampled stream of the discharge stack gases.

A conveyor belt was installed to convey the dewatered sludge material from ground level up to the inlet feed hopper located at hearth No. 3. Because of the small size of the furnace, sludge cakes were physically broken up into small chunks prior to loading on the conveyor feed belt. A multibladed chopping tool was devised for this purpose. Upon entering the feed hopper, the cake chunks are screw conveyed into the furnace to undergo incineration. Therein, the solids are conveyed spirally around the hearth floor towards a central exit port. The solids fall through this port to the hearth below, i.e. hearth No. 4; therein, they are conveyed spirally outward toward the furnace wall where an annular exit port, i.e. the entrance to hearth No. 5, is located. Following central conveyance across the floor of hearth No. 5 and outward conveyance across the floor of hearth No. 6, the remaining solids, i.e. the ash residue, fall into a hopper and are discharged from the furnace by screw conveyance through a water jacketed conduit. The discharged ash clinkers are fed to a hammer mill to be pulverized to flyash constituency for use as a sludge conditioning aid.

The conveyance of the solids across the individual hearths is accomplished by plow teeth attached to horizontally suspended arms. The arms are fixed to a shaft running vertically through the center of the furnace to a variable speed drive unit. During operation, the shaft is rotated about its vertical axis at a preset speed. The attached arms (four in each hearth situated crosswise) sweep above and across the hearth floor dragging the plow teeth through the residing solids. The configuration and arrangement of the plow teeth along each arm is such that the solids are plowed back and forth along the spiral path of movement. The net effect is one of providing greater turnover of the residing solids. This increases the frequency of exposure to the overlying gases which, in turn, enhances the rapidity of the incineration process.

A majority of the residual moisture in the dewatered sludge fed to the furnace is removed by evaporation on hearth No. 3. Ignition and flame burning take place on hearth No. 4. On hearth No. 5, the fixed hydrocarbons are burned in glowing charcoal fashion. Residual burning and preliminary cooling of the ash residue occur in lowermost hearth No. 6. The uppermost hearths (Nos. 1 and 2) are used for the afterburning of generated combustion gases drawn upward by the draft induction fan from the hearths below. Water is sprayed into the hot afterburned gases exiting hearth No. 1. The partially cooled gases are then directed into a water scrubber for further cooling and, more importantly, for removal of any fine particulate matter which may have been carried out of the furnace in the gas stream. The cooled clean gases were then discharged to the atmosphere.

CONDITIONING SYSTEMS

Four forms of sludge conditioning were evaluated as part of the Districts' research work. These included heat conditioning, conditioning with cationic polymers, chemical conditioning with ferric chloride and/or lime, and flyash conditioning. In this country, polymers and chemicals are probably the most conventional and widely used means of conditioning sewage sludges for dewatering purposes. Flyash, as a sludge conditioning aid, is frequently utilized by installations employing incineration for solids disposal. The use of heat treatment as a means of conditioning sludges prior to dewatering has been practiced quite extensively in Europe since its introduction in 1932. During the last decade, however, a few heat treatment installations have been showing up across the United States. Although some were not too successful at first, rapid engineering and developmental changes have resulted in processes which are gaining wide acceptance.

In the subsequent text, data results from Porteous heat conditioning of JWPCP digested sludge are presented and discussed. Pertinent information on polymer, chemical and flyash conditioning is also presented as it related to this work.

PORTEOUS HEAT TREATMENT

Basically, the heat conditioning process is continuous pressure cooking. Waste sludges are heated under pressure to some temperature greater than 310°F (155°C). Under these conditions, proteinaceous material surrounding a sludge particle is hydrolized to a large extent. Thus, bound water, i.e. that originally bound to the particle by this material, is released thereby permitting each particle in the fluid medium to behave as its specific gravity intended it to and not as some sort of gelatinous colloid.

Obviously, the overall effectiveness of this process is dependent on the temperature necessary to carry out this reaction. Also, sufficient reaction time is necessary to insure the completeness of bound water release. At the temperatures under consideration, however, other side effects do take place which warrant some mention. These include the thermal transfer of material from the suspended to the dissolved phase and the thermal decomposition of some organics to less complex forms and/or gaseous by-products. Since the degree to which these side effects occur is increased with increased reaction time and temperature, it becomes apparent that the most optimum temperature-time combination for sludge conditioning is that employing the minimum temperature necessary to effectively destroy the gel-like structure.

Within the operational limits of the Porteous pilot plant itself, the effect of two reactor cooking times (30 and 40 minutes) were investigated. At each detention time, primary digested sludge was cooked at each of several temperatures ranging from 330°F to 395°F (165°C to 200°C). During each run, samples of primary digested sludge feed and the thermally treated product, hereinafter referred to as "portrate", were taken and later analyzed in the laboratory for their suspended and dissolved solid contents. Corresponding fixed and volatile fractions of each were also determined. In addition, each sample was analyzed for total and soluble COD. Data results from this work are presented in Tables 4 thru 7.

At the end of each time-temperature run, a 2-liter grab sample of portrate was collected in a graduated cylinder. The quiescent settling characteristics of this material were then observed over a one-hour period of time. At the end of this period, 100-ml samples of both the top and bottom suspension layers within the cylinder were each pipetted off and analyzed for their suspended and dissolved solid contents. Corresponding fixed and volatile fractions of each were also determined. The results of these analyses are presented in Tables 8 and 9.

Specifically, the data of Tables 4 thru 7 provide much insight into some of the physical transformations that had taken place within the sludge medium as a result of thermal conditioning. Regardless of the cooking time or cooking temperature investigated, the heat conditioning process effected both an increase in dissolved solids

Table 4: DATA SUMMARIZING THE SOLID CHARACTERISTICS OF 'JWPCP' PRIMARY DIGESTED SLUDGE BOTH BEFORE AND AFTER 30 MINUTES OF COOKING AT VARIOUS REACTOR TEMPERATURES.

REACTOR TEMPERATURE	REACTOR FEED SOLIDS DATA*						PORTRATE SOLIDS DATA					
	Suspended Form			Dissolved Form			Suspended Form			Dissolved Form		
-°F-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-
330	3.27	1.99	1.27	0.17	0.05	0.12	3.06	1.74	1.32	0.42	0.33	0.09
340	3.21	1.99	1.22	0.18	0.11	0.07	2.41	1.35	1.06	0.53	0.49	0.04
350	3.27	1.99	1.28	0.19	0.09	0.10	2.74	1.53	1.21	0.45	0.40	0.05
360	3.46	2.12	1.34	0.18	0.07	0.11	2.65	1.50	1.15	0.52	0.44	0.08
370	3.35	2.14	1.21	0.21	0.09	0.12	2.51	1.40	1.11	0.53	0.46	0.07
380	3.40	2.16	1.24	0.19	0.07	0.12	2.76	1.54	1.21	0.55	0.46	0.09
390	3.29	2.06	1.24	0.19	0.10	0.09	2.54	1.33	1.21	0.50	0.45	0.05
395	3.32	1.84	1.48	0.16	0.06	0.10	2.79	1.35	1.44	0.44	0.36	0.08

* The solid values reported have been corrected for dilution with grinder seal water and condensed steam.

Unit Conversions: $0.56\ (^{o}F-32) = (^{o}C)$

$(\%\ \text{Solids}) \times 10{,}000 = (mg/l)$

Table 5: DATA SUMMARIZING THE SOLIDS CHARACTERISTICS OF 'JWPCP' PRIMARY DIGESTED SLUDGE BOTH BEFORE AND AFTER 40 MINUTES OF COOKING AT VARIOUS REACTOR TEMPERATURES.

REACTOR TEMPERATURE	REACTOR FEED SOLIDS DATA*						PORTRATE SOLIDS DATA					
	Suspended Form			Dissolved Form			Suspended Form			Dissolved Form		
-°F-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-
330	3.03	-	-	0.21	-	-	2.50	-	-	0.39	-	-
335	3.06	-	-	0.20	-	-	2.55	-	-	0.42	-	-
340	4.75	-	-	0.22	-	-	3.87	-	-	0.56	-	-
345	3.53	2.23	1.30	0.22	0.10	0.12	2.65	1.58	1.07	0.40	0.29	0.11
350	3.11	1.91	1.20	0.20	0.08	0.12	2.39	1.32	1.07	0.40	0.30	0.10
355	3.08	1.88	1.20	0.14	0.02	0.12	2.49	1.38	1.11	0.42	0.33	0.09
360	3.27	1.98	1.29	0.18	0.04	0.14	2.62	-	-	0.38	-	-
365	3.14	1.79	1.35	0.16	0.03	0.13	2.47	1.21	1.26	0.41	0.32	0.09
370	3.23	1.49	1.74	0.13	0.07	0.06	2.32	-	-	0.46	0.41	0.05
375	3.04	1.73	1.31	0.25	0.11	0.14	2.39	1.24	1.15	0.49	0.39	0.10
380	2.96	1.76	1.20	0.22	0.08	0.13	2.33	1.19	1.14	0.51	0.43	0.08
385	3.47	2.04	1.43	0.18	0.02	0.16	3.04	1.57	1.47	0.45	0.34	0.11
395	3.24	1.79	1.45	0.15	0.06	0.09	2.60	1.28	1.32	0.44	0.39	0.05

* The solids values reported have been corrected for dilution with grinder seal water and condensed steam.

Unit Conversions:

0.56 (°F-32) = (°C)
(% Solids) x 10,000 = (mg/l)

Table 6: DATA SUMMARIZING THE "COD" CHARACTERISTICS OF 'JWPCP' PRIMARY DIGESTED SLUDGE BOTH BEFORE AND AFTER 30 MINUTES OF COOKING AT VARIOUS REACTOR TEMPERATURES.

REACTOR TEMPERATURE -°F-	REACTOR FEED "COD" DATA*		PORTRATE "COD" DATA	
	Total -mg/1-	Soluble -mg/1-	Total -mg/1-	Soluble -mg/1-
330	32,300	290	30,700	4,450
340	34,840	290	32,350	5,550
350	35,460	289	-	5,800
360	35,785	286	31,650	6,280
370	33,074	268	-	6,070
380	34,842	270	-	6,200
390	35,450	275	31,900	6,300
395	34,290	243	29,300	6,400

* The "COD" values reported have been corrected for dilution with grinder seal water and condensed steam.

Unit Conversions: 0.56 (^{o}F-32) = (^{o}C)

Table 7: DATA SUMMARIZING THE "COD" CHARACTERISTICS OF 'JWPCP' PRIMARY DIGESTED SLUDGE BOTH BEFORE AND AFTER 40 MINUTES OF COOKING AT VARIOUS REACTOR TEMPERATURES.

REACTOR TEMPERATURE -^{o}F-	REACTOR FEED "COD" DATA*		PORTRATE "COD" DATA	
	Total -mg/l-	Soluble -mg/l-	Total -mg/l-	Soluble -mg/l-
355	41,440	330	38,400	5,280
360	34,620	280	36,300	4,260
365	33,910	380	29,600	5,330
370	32,330	310	28,500	5,910
375	30,390	240	24,300	5,670
380	35,300	280	28,900	5,950
385	36,040	310	27,600	6,830
395	32,950	280	29,300	6,400

* The COD values reported have been corrected for dilution with grinder seal water and condensed steam.

Unit Conversions: 0.56 (^{o}F-32) = (^{o}C)

Table 8: DATA SUMMARIZING THE QUIESCENT SETTLING* CHARACTERISTICS OF SUSPENDED SOLIDS IN 30-MINUTE HEAT-CONDITIONED DIGESTED SLUDGE**

REACTOR TEMPERATURE	SOLID CONC. IN "UPPER" 100 ml after SETTLING						SOLID CONC. IN "LOWER" 100 ml after SETTLING					
	Total Form			Suspended Form			Total Form			Suspended Form		
-°F-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-
330	0.98	0.66	0.32	0.56	0.33	0.23	6.05	3.72	2.33	5.63	3.38	2.25
340	0.92	0.66	0.26	0.50	0.32	0.18	6.72	3.98	2.74	6.30	3.64	2.66
350	1.10	0.75	0.35	0.65	0.36	0.29	6.76	3.88	2.88	6.31	3.48	2.83
360	0.89	0.65	0.24	0.37	0.20	0.17	6.42	3.96	2.46	5.90	3.52	2.38
370	0.81	0.61	0.20	0.30	0.18	0.12	7.01	4.18	2.83	6.50	3.76	2.74
380	0.88	0.66	0.22	0.33	0.20	0.13	6.98	4.10	2.88	6.44	3.65	2.79
390	0.91	0.67	0.24	0.42	0.23	0.19	7.24	4.11	3.13	6.74	3.66	3.08
395	0.76	0.57	0.18	0.33	0.15	0.18	6.42	3.23	3.19	6.00	2.81	3.19

* Data were acquired from samples taken after one-hour of settling in a 2-liter graduated cylinder.

** All tabulated data pertain to the thermal processing of JWPCP primary digested sludge.

Unit Conversions; $0.56\ (^{\circ}F-32) = (^{\circ}C)$

$(\%\ Solids) \times 10{,}000 = (mg/l)$

Table 9: DATA SUMMARIZING THE QUIESCENT SETTLING* CHARACTERISTICS OF SUSPENDED SOLIDS IN 40-MINUTE HEAT-CONDITIONED DIGESTED SLUDGE**

REACTOR TEMPERATURE	SOLID CONC. IN "UPPER" 100 ml after SETTLING						SOLID CONC. IN "LOWER" 100 ml after SETTLING					
	Total Form			Suspended Form			Total Form			Suspended Form		
-°F-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-
330	0.75	0.47	0.28	0.36	-	-	5.76	3.17	2.59	5.37	-	-
335	0.84	0.56	0.28	0.42	-	-	6.36	3.58	2.78	5.94	-	-
340	0.79	0.62	0.18	0.23	-	-	5.25	3.50	1.75	4.69	-	-
345	0.66	0.44	0.22	0.26	0.15	0.11	5.34	3.30	2.04	4.94	3.01	1.93
350	0.58	0.42	0.16	0.18	0.11	0.07	5.38	3.14	2.24	4.98	2.83	2.15
355	0.69	0.47	0.22	0.27	0.14	0.13	5.83	3.29	2.54	5.40	2.96	2.44
360	0.80	0.54	0.26	0.42	-	-	5.97	3.37	2.60	5.58	-	-
365	0.79	0.53	0.26	0.39	0.21	0.18	5.95	3.13	2.82	5.54	2.80	2.74
370	0.81	0.59	0.22	0.36	0.18	0.18	6.41	3.86	2.55	5.96	3.46	2.50
375	0.78	0.56	0.22	0.29	0.16	0.13	5.66	3.05	2.61	5.17	2.66	2.51
380	0.78	0.60	0.18	0.26	0.17	0.09	6.07	3.16	2.91	5.56	2.73	2.83
385	0.74	0.51	0.23	0.29	0.17	0.12	6.59	3.36	3.23	6.14	3.01	3.13
395	0.82	0.59	0.23	0.39	0.21	0.18	6.61	3.36	3.25	6.18	2.97	3.21

* Data were acquired from samples taken after one-hour of settling in a 2-liter graduated cyclinder.

** All tabulated data pertain to the thermal processing of JWPCP primary digested sludge.

Unit Conversions: 0.56 (°F-32) = (°C)
(% Solids) x 10,000 = (mg/1)

and a decrease in the suspended solids content. Most of this change took place in the volatile fraction of each, with the fixed fractions remaining relatively constant. The effect was NOT a corresponding one since there were some losses in total volatile matter.

Accordingly, two phenomena occurred while heat treating the JWPCP's primary digested sludge. First the volatile material injected into the reactor vessel underwent thermal breakdown to some degree. This resulted in gaseous by-products which were carried off with the vented reactor gases. Second, some of the suspended volatile material was driven into the soluble phase. No correlation existed between the degree to which each of these phenomena occurred and the time or temperature of the heat conditioning reaction.

The thermal solubilization of organics which took place during heat conditioning of digested sludge is evidenced by the soluble COD data of Tables 6 and 7. Soluble COD did appear to increase with increased cooking temperature in the ranges investigated. No correlation, however was observed with respect to cooking time.

The data of Tables 8 and 9 manifest the difference in the degree of sludge conditioning which took place at the various reaction temperatures investigated. At the lower, 30-minute reactor cooking time (Table 8), increased cooking temperatures from 330°F to 360°F (165°C to 180°C) resulted in a decrease in the concentration of suspended material remaining in the UPPER 100-ml layer after one hour of quiescent settling. Further temperature increases up to 395°F (200°C) did nothing to improve this condition. A similar trend was observed at the 40-minute reactor cooking time (Table 9). However, the breakpoint occurred at 350°F (175°C) instead. Further temperature increases from 350°F to 395°F (175°C to 200°C) provided no inducement for additional settling of particulate matter from the UPPER 100-ml suspension layer. In fact, there was some indication that a minor reversal was taking place.

No relationship between suspended solid concentrations in the LOWER 100-ml suspension layers and cooking temperature was evident at either the 30- or 40-minute cooking time. Observed concentrations in the lower layer appeared to be a function of the initial solids content of the feed prior to cooking.

It was apparent from Tables 8 and 9 that, with respect to the two breakpoint temperatures, the additional 10 minutes of cooking time, i.e. 40 minutes at 350°F (175°C), did impart slightly better settling qualities to the suspended material in portrate. It was therefore decided this was the OPTIMUM time-temperature combination for heat conditioning of the JWPCP's primary digested sludge. All followup studies concerned with the dewatering of portrate were conducted with digested sludge thermally conditioned under these conditions.

POLYMER CONDITIONING

The addition of polyelectrolytes to sludge is carried out to improve the coagulation and flocculation of fine solid particles held in suspension in the liquid. Polyelectrolytes (commonly referred to as polymers) are water-soluble organic molecules with molecular weights up to 10 million. These polymers contain chemical groups which are capable of undergoing electrolytic dissociation in solution, resulting in long-chained highly charged ions. Polymers are classified into three different types (anionic, cationic, nonionic) depending on their ionic character.

Fine particles dispersed in water are held in suspension primarily because of their extremely small size. A small particle has a high surface area to mass ratio. Consequently, surface phenomena, such as state of hydration and electrostatic repulsion, tend to negate the effects of gravitational forces, thus preventing aggregation and sedimentation of solid particles. Addition of polymers to a solution increases sedimentation in two ways. First, the long-chained polymer molecule chemically and/or physically bonds itself to the adsorbent surfaces of sludge particles. The net effect is the formation of bridges between these otherwise discrete particles, resulting in flocculation. Also, the charge-carrying polymer reduces the net electrical repulsive forces at particle surfaces, thus decreasing the resistence of the particles to form aggregates. The action of anionic polymers is apparently mostly due to physical attachment, whereas cationic polymers are effective primarily because of their ability to reduce electrical repulsion. Once contact between particles is achieved, the forces of attraction (Van der Waals forces) become significant enough to resist breakup of the particles through the mild agitation necessary to induce flocculation. Consequently, aggregates accumulate with lower surface area to mass ratios, and sedimentation by gravity occurs more readily.

The effects of using cationic polyelectrolytes as a sludge conditioning agent in the various pilot plant units are discussed in detail later in this report.

CHEMICAL CONDITIONING

Chemicals are added to sludges to coagulate and flocculate the fine particles which, under normal conditions, remain discreetly suspended in the liquid phase. In primary digested sludges, this stability is attributable in part to the particles' net negative charge. Hence, neutralization of this charge is necessary before coagulation can occur. Multivalence cations are generally used for this purpose. Their addition to the sludge serves to depress the electronegativity of the charged particles, thereby reducing the zeta potential to a level below the Van der Walls attractive forces. In general, the coagulation and precipitating power of the added cations geometrically increases with the valence. When necessary, alkalinity is also added.

In this investigation, laboratory studies revealed that chemical coagulation of the suspended material in the JWPCP digested sludge was best under conditions of high pH. Accordingly, lime was selected to accomplish this in the pilot plant studies. In addition, ferric chloride ($FeCl_3$) was selected as the charge neutralizing agent for coagulation.

The addition of lime aids in the formation of floc particles by increasing the (OH^-) radical in solution. Under these conditions, the followup addition of the ferric salt results in the formation of an insoluble ferric hydroxide. The basic reaction governing this formation is

$$Fe^{3+} + 3\ OH^- \longrightarrow Fe(OH)_3$$

where the solubility product $(Fe^{3+})(OH^-)^3 = 10^{-36}$.

The lime used in the test program was purchased in dry powdered form as calcium hydroxide, $Ca(OH)_2$, with an approximate purity of 95 percent. Lime conditioning in conjunction with pressure filtration tests was accomplished by directly adding a weighted amount of the dry material (as received) to a known volumetric quantity of sludge residing in the unit's conditioning tank. In all other cases, liquid solutions of this material were batched for controlled feeding to the unit or system being evaluated. Throughout the report, lime dosages--stated in terms of $Ca(OH)_2$--actually denote the weight of dry material (including impurities) added per unit weight of dry sludge solids.

Buchner Funnel tests run by the Districts' laboratory personnel indicated that chemical conditioning of the JWPCP primary digested sludge for pilot plant dewatering would be optimized in the ferric chloride and/or lime dosage ranges of 40-120 lbs/ton (20-60 kg/metric ton) and 400-800 lbs/ton (200-400 kg/metric ton) as $Ca(OH)_2$ respectively. Data results regarding dewatering studies conducted with chemical dosages in these ranges are presented later in this report.

FLYASH CONDITIONING

Flyash is a complex, heterogeneous inert material whose physical and chemical properties are, for the most part, dependent on its source. It is these properties which affect its action as a sludge conditioner. When added to a sludge mixture, sludge particles become bonded to the surface of the flyash particles by means of chemical and/or electrostatic interactions. Additional alkalinity is sometimes necessary to enhance these reactions. The overall effect is such that an intimately mixed three-dimensional lattice is formed, the strength and rigidity of which is dependent on the properties of both the sludge and flyash particulate matter. Such a structure enables the development of numerous passages or pores to occur during dewatering and compaction of the cake solids, thus allowing for unrestricted flowthrough movement of the fluid medium. This results in a dewatered sludge cake of lower residual moisture content.

In this study, flyash conditioning was only evaluated in conjunction with dewatering by pressure filtration. Incineration of the various dewatered sludge cakes produced an ash residue which, when pulverized, became the resulting flyash conditioning material.

DEWATERING SYSTEMS

The availability of the various pilot plant dewatering equipment enabled a variety of conditioning-dewatering schemes to be set up and evaluated. Some of the units were assessed as to their capabilities for dewatering centrate from the existing centrifuge station at the JWPCP; for purposes of discussion, the term "Bird centrate" will be used hereafter when referring to the feed material of such schemes. Also, much of the equipment was evaluated using digested sludge as the feed material. Overall, the evaluations incorporated the various conditioning steps discussed in the previous section.

Regarding those schemes incorporating heat conditioning, consideration was only given to the processing of optimally prepared portrate sludge, i.e. digested sludge cooked at 350°F (175°C) for 40 minutes. First, the picket thickening characteristics of portrate were investigated. Other dewatering equipment were then evaluated as to their individual ability to dewater the thickened portrate. Some studies were also conducted to assess whether the cooked sludge could be directly dewatered without any intermediate thickening step. Regarding portrate centrifugation studies, the effect of secondary conditioning with a cationic polymer was also evaluated.

The following is a detailed presentation of the data generated from the research work. In this regard, the details and capabilities of each dewatering unit are presented separately and discussed.

PICKET THICKENING OF COOKED DIGESTED SLUDGE

Presented in Figure 13 is a flow schematic of the experimental setup used for evaluating the picket thickening properties of optimally heat-conditioned digested sludge. As noted, a small storage tank and a variable speed feed pump were incorporated in series between the Porteous unit and the thickening tank. Portrate, intermittently discharged to and accumulated in the storage tank, would serve as the reservoir from which it would be steadily pumped at various feedrates to the clarifier. In accordance with the output from the Porteous unit, a maximum steady state feedrate of 3.4 gpm (0.21 l/sec) would be possible. The storage tank was equipped with an overflow drainage line, thus providing excess storage relief during periods when clarifier feedrates below maximum were being investigated.

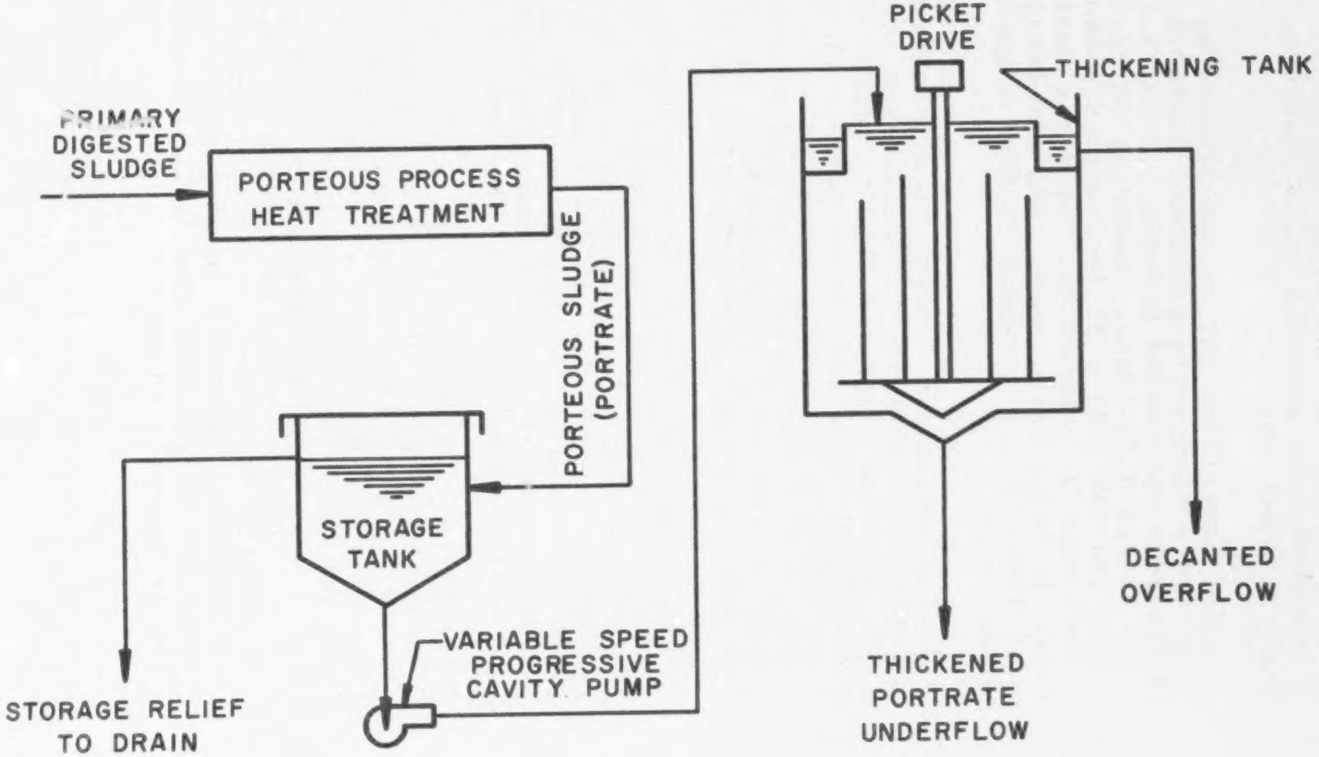
Overall, the following two capabilities are seen to have been built into this system. First, a continuously fed clarifier would provide a continuous steady stream of decant (overflow) from the overflow weir of the thickening tank. Second, cessation of the tank feed would enable thickening of the tank's contents without overflow.

The manner in which the thickening tests were conducted was as follows. At the beginning of each test run, cooked sludge was fed directly from the Porteous unit into the clarifier. The picket thickener remained de-energized during filling. When the tank became full, the portrate was then diverted into the storage tank and pump assembly for controlled feeding at one of four test feed rates. The picket thickener was simultaneously energized. Following one hour of picket thickening with continuous overflow, a one-liter sample of each of the overflow and underflow was taken. Time permitting, a second set of samples was taken following a second hour of picket thickening with continuous overflow. The feeding of portrate to the clarifier was then discontinued. The material still remaining in the tank, however, was allowed to picket thicken overnight. Following 16 hours of picket thickening without continuous overflow, samples of both the upper and lower suspension layers were taken.

FIGURE 13

Schematic flow diagram

Equipment used to evaluate the picket thickening properties of heat conditioned digested sludge


PRIMARY DIGESTED SLUDGE
PORTEOUS PROCESS HEAT TREATMENT
PORTEOUS SLUDGE (PORTRATE)
STORAGE TANK
STORAGE RELIEF TO DRAIN
VARIABLE SPEED PROGRESSIVE CAVITY PUMP
PICKET DRIVE
THICKENING TANK
THICKENED PORTRATE UNDERFLOW
DECANTED OVERFLOW

All samples were analyzed for their total, dissolved and respective fixed and solid fractions. Corresponding suspended and volatile solid fractions were determined by subtraction.

Data summarizing the picket thickening properties of portrate sludge are presented in Table 10. The clarifier feedrate was varied between 1.2 and 3.4 gpm (0.08 and 0.21 l/sec) resulting in overflow rates between 225 and 635 gpd/sq ft (9.2 and 25.9 cu m/day/sq m). The test runs at each of the indicated feedrates were carried out in triplicate. Hence, the tabulated values shown in Table 10 are averages of data acquired from individual test runs.

During continuous feeding (a situation which provided continuous overflow) an equilibrium state of operation was achieved after one hour of picket thickening. Continued operation for an additional one-hour period served only to thicken the material in the bottom of the tank. Overflow quality remained relatively unchanged as seen by the 2-hr data taken when the overflow rate was either 375 or 560 gpd/sq ft (15.3 or 22.8 cu m/day/sq m).

With respect to the one-hour thickening runs, the average concentration of suspended solids in the decanted overflow decreased with decreasing feed rates. The effect is graphically depicted in Figure 14 of this report. At an overflow rate of 635 gpd/sq ft (25.9 cu m/day/sq m) a decanted liquor resulted containing 0.53% (5300 mg/l) of suspended material. At the lower 225 gpd/sq ft (9.2 cu m/day/sq m) overflow rate, the suspended solids content in the decantate was 0.37% (3700 mg/l). The dashed portion of the curve at the bottom is a projection based on the average of the suspended solids remaining in the UPPER suspension layer following overnight thickening. This value of 1900 mg/l (0.19%) represents the average absolute minimum to which suspended solids in the overflow could be reduced by this type of gravity thickening operation; it also indicates that an absolute maximum of 95 percent of the suspended material could be removed from the JWPCP's digested sludge by the system as a whole.

In all cases, picket thickening increased the suspended solid concentrations in the underflow suspension layer of

Table 10 : DATA SUMMARIZING THE EFFECT OF CLARIFIER OVERFLOW RATE ON THE PICKET THICKENING PROPERTIES OF COOKED DIGESTED SLUDGE*

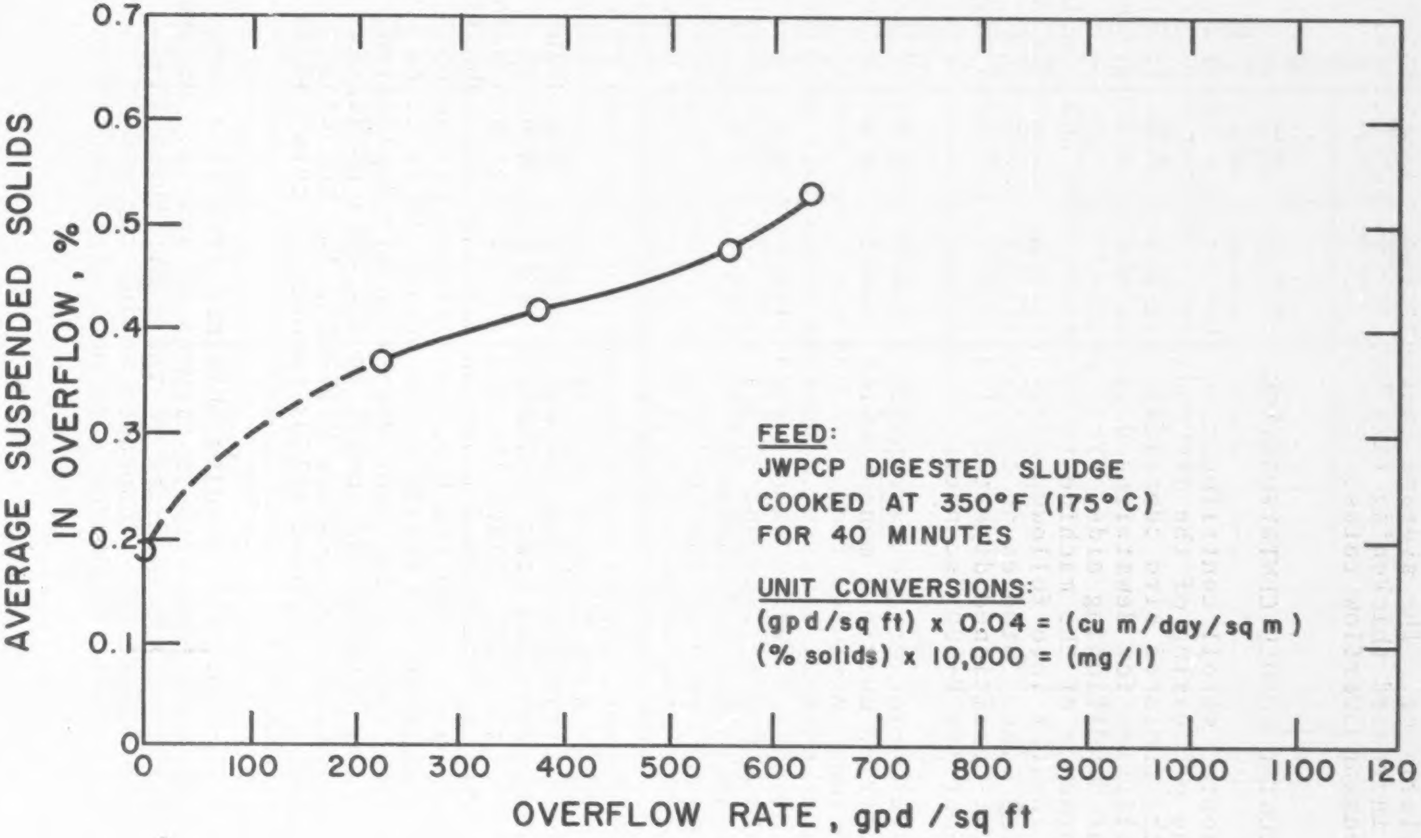
CLARIFIER OVERFLOW RATE -gpd/sq ft-	PICKET THICKENING TIME -hr-	WITH or WITHOUT CONTINUOUS OVERFLOW	AVERAGE SUSPENDED SOLIDS IN THICKENING TANKS					
			UPPER Suspension Layer			LOWER Suspension Layer		
			Total -%-	Volatile -%-	Fixed -%-	Total -%-	Volatile -%-	Fixed -%-
225	1.0	With	0.37	0.21	0.16	7.78	4.33	3.45
	16.0	Without	0.19	0.12	0.07	10.82	6.00	4.82
375	1.0	With	0.42	0.25	0.17	6.29	3.62	2.67
	2.0	With	0.39	0.24	0.15	7.82	4.49	3.33
	16.0	Without	0.19	0.13	0.06	10.30	5.81	4.49
560	1.0	With	0.48	0.27	0.21	7.07	4.10	2.97
	2.0	With	0.48	0.28	0.20	9.97	5.67	4.30
	16.0	Without	0.17	0.09	0.08	14.93	8.51	6.42
635	1.0	With	0.53	0.29	0.24	6.14	3.59	2.55
	16.0	Without	0.20	0.16	0.04	7.96	4.51	3.44

*All data pertain to JWPCP waste digested sludge cooked at 350°F (175°C) for 40 minutes. Tabulated values are averages of individual data acquired from triplicate runs.

Unit Conversions: (gpd/sq ft) x 0.0408 = (cu m/day/sq m)
(% Solids) x 10,000 = (mg/l)

FIGURE 14

Suspended solids in decantate as a function of overflow rate in a picket thickening clarifier



the clarifier. The average concentration values increased with increased thickening time but varied randomly with increasing overflow rates.

HORIZONTAL SCROLL CENTRIFUGATION

Horizontal scroll centrifugation studies were restricted to the processing of the JWPCP digested sludge. Initially, the isolated Bird centrifuge was assessed as to its capabilities for dewatering digested sludge without the use of conditioning aids. This enabled the base performance of the machine to be established and provided much insight into followup work utilizing polymer conditioning aids. Studies on the centrifugal dewatering of heat-conditioned digested sludge were conducted with the Sharples P-600 decanter.

The evaluation of the base performance of the Bird decanter was carried out in a manner which enabled the effect of variations in sludge feed rate and bowl pool depth to be independently assessed. Considered in this respect were primary digested sludge feedrates between 200 and 400 gpm (12.6 and 25.2 l/sec) and pool depths between 1.0 and 3.4 inches (2.5 and 8.6 cm). The rotational speed of the bowl was held constant at 1300 rpm. The differential speed, i.e. the speed difference between the bowl and scroll, remained fixed at 15.3 rpm. During all test runs, the chemical chamber and injection tubes were purged with 7 gpm (0.4 l/sec) of water to prevent backflow intrusion of the sludge material. The data obtained from this test evaluation are presented in Tables 11 thru 15. Since the Bird centrifuge had been completely reconditioned prior to testing, the tabulated results demonstrated the base performance of the machine under conditions of little or no wear. It is to be noted that many of the runs were randomly duplicated, thus adding support and surety to the data obtained. Tabulated data averages are presented for the cake qualities and suspended solids recoveries obtained in the duplicate runs.

The base performance results obtained from this work are graphically depicted in Figures 15 and 16. Regardless of the sludge feedrate to the centrifuge, the general trend was for suspended solids capture to increase and cake dryness to decrease as pool depth was increased.

Table 11: DATA* SUMMARIZING THE EFFECT OF VARYING POOL DEPTHS ON THE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE WHEN FED PRIMARY DIGESTED SLUDGE IN A 200-GPM FLOWSTREAM.

POOL DEPTH -inches-	SUSPENDED SOLIDS CONCENTRATION				SUSPENDED SOLIDS RECOVERY -%-	
	Digested Sludge Feed** -%-	Centrate -%-	Centrifuged Cake -%-			
			Individual	Average	Individual	Average
1.0	2.68	1.87	29.4	34.8	32.2	28.1
1.0	3.25	2.52	40.2		23.9	
1.5	3.29	2.29	31.5	31.5	32.8	32.8
2.0	3.17	2.08	23.9	25.1	37.5	37.2
2.0	3.26	2.16	26.2		36.9	
2.5	3.77	2.11	30.0	30.1	47.5	46.3
2.5	3.43	1.99	30.3		45.0	
3.0	3.73	2.09	24.6	24.6	48.1	48.1
3.5	3.73	1.86	20.6	20.6	55.2	55.2

*All data pertain to dewatering of JWPCP primary digested sludge in a 36-inch x 96-inch horizontal scroll centrifuge.

**Reported values are corrected for dilution with 7 gpm of water purging through the chemical chamber.

Unit Conversions:

(inches) x 2.54 = (cm)
(% Solids) x 10,000 = (mg/1)
(gpm) x 0.0631 = (1/sec)

Table 12: DATA* SUMMARIZING THE EFFECT OF VARYING POOL DEPTHS ON THE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE WHEN FED PRIMARY DIGESTED SLUDGE IN A 250-GPM FLOWSTREAM

POOL DEPTH -inches-	SUSPENDED SOLIDS CONCENTRATION				SUSPENDED SOLIDS RECOVERY -%-	
	Digested Sludge Feed** -%-	Centrate -%-	Centrifuged Cake -%-			
			Individual	Average	Individual	Average
1.0	3.32	2.61	37.0	37.0	22.9	22.9
1.5	3.20	2.36	36.5	36.5	28.1	28.1
2.0	3.55	2.44	31.8	31.8	34.1	34.1
2.5	3.47	2.23	29.8	29.8	38.8	38.8
3.0	3.63	2.23	23.0	23.9	42.8	42.5
3.0	3.05	1.86	24.8		42.1	
3.4	3.41	1.95	22.6	22.6	46.9	46.9

* All data pertain to dewatering of JWPCP primary digested sludge in a 36-inch x 96-inch horizontal scroll centrifuge.

** Reported values are corrected for dilution with 7 gpm of water purging through the chemical chamber.

Unit Conversions:
(inches) x 2.54 = (cm)
(% Solids) x 10,000 = (mg/l)
(gpm) x 0.0631 = (l/sec)

Table 13; DATA* SUMMARIZING THE EFFECT OF VARYING POOL DEPTHS ON THE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE WHEN FED PRIMARY DIGESTED SLUDGE IN A 300-GPM FLOWSTREAM.

POOL DEPTH	SUSPENDED SOLIDS CONCENTRATION				SUSPENDED SOLIDS RECOVERY -%-	
	Digested Sludge Feed**	Centrate	Centrifuged Cake -%-			
-inches-	-%-	-%-	Individual	Average	Individual	Average
1.0	3.30	2.62	41.7	41.5	22.0	21.2
1.0	3.01	2.43	41.3		20.4	
1.5	3.48	2.51	40.7	38.5	29.7	26.3
1.5	3.01	2.37	36.2		22.9	
2.0	3.41	2.42	33.9	35.3	31.4	28.2
2.0	3.14	2.41	36.6		25.0	
2.5	3.29	2.25	30.1	31.9	34.1	35.3
2.5	3.39	2.24	33.7		36.5	
3.0	3.30	2.22	26.2	26.7	35.9	39.0
3.0	3.44	2.11	27.1		42.0	
3.4	3.59	2.22	25.0	25.0	42.0	42.0

* All data pertain to dewatering of JWPCP primary digested sludge in a 36-inch x 96-inch horizontal scroll centrifuge.

** Reported values are corrected for dilution with 7 gpm of water purging through the chemical chamber.

Unit Conversions:
(inches) x 2.54 = (cm)
(% Solids) x 10,000 = (mg/1)
(gpm) x 0.0631 = (1/sec)

Table 14: DATA* SUMMARIZING THE EFFECT OF VARYING POOL DEPTHS ON THE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE WHEN FED PRIMARY DIGESTED SLUDGE IN A 350-GPM FLOWSTREAM.

POOL DEPTH -inches-	SUSPENDED SOLIDS CONCENTRATION Digested Sludge Feed** -%-	Centrate -%-	Centrifuged Cake -%- Individual	Centrifuged Cake -%- Average	SUSPENDED SOLIDS RECOVERY -%- Individual	SUSPENDED SOLIDS RECOVERY -%- Average
1.0	3.52	2.90	41.9	41.9	19.1	19.1
1.5	3.41	2.71	39.8	39.8	22.0	22.0
2.0	3.40	2.56	36.4	36.4	26.4	26.4
2.5	3.46	2.42	32.5	32.0	32.5	33.3
2.5	3.46	2.37	31.5		34.1	
3.0	3.34	2.32	32.1	30.5	33.1	35.4
3.0	3.49	2.28	28.8		37.7	
3.4	3.31	2.14	28.1	24.2	38.3	39.8
3.4	3.46	2.19	20.2		41.2	

* All data pertain to dewatering of JWPCP primary digested sludge in a 36-inch x 96-inch horizontal scroll centrifuge.

** Reported values are corrected for dilution with 7 gpm of water purging through the chemical chamber.

Unit Conversions:
(inches) x 2.54 = (cm)
(% Solids) x 10,000 = (mg/1)
(gpm) x 0.0631 = (1/sec)

Table 15 : DATA* SUMMARIZING THE EFFECT OF VARYING POOL DEPTHS ON THE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE WHEN FED PRIMARY DIGESTED SLUDGE IN A 400-GPM FLOWSTREAM.

POOL DEPTH -inches-	SUSPENDED SOLIDS CONCENTRATION				SUSPENDED SOLIDS RECOVERY -%-	
	Digested Sludge Feed** -%-	Centrate -%-	Centrifuged Cake -%-			
			Individual	Average	Individual	Average
1.0	3.10	2.43	41.2	40.8	22.8	22.0
1.0	3.44	2.76	40.5		21.2	
1.5	3.25	2.49	40.7	39.5	24.9	23.8
1.5	3.45	2.73	38.2		22.7	
2.0	3.12	2.23	41.6	38.2	30.4	28.2
2.0	3.48	2.65	34.8		25.9	
2.5	3.40	2.43	30.4	30.4	31.2	31.2
3.0	3.05	2.07	30.9	29.4	34.5	32.5
3.0	3.34	2.41	28.0		30.5	
3.4	3.01	1.91	25.6	25.6	39.2	38.1
3.4	3.47	2.31	25.5		36.9	

* All data pertain to dewatering of JWPCP primary digested sludge in a 36-inch x 96-inch horizontal scroll centrifuge.

** Reported values are corrected for dilution with 7 gpm of water purging through the chemical chamber.

Unit Conversions:

(inches) x 2.54 = (cm)
(% Solids) x 10,000 = (mg/1)
(gpm) x 0.0631 = (1/sec)

FIGURE 15

The effect of decanter pool depth on the centrifugal recovery of suspended solids from unconditioned primary digested sludge

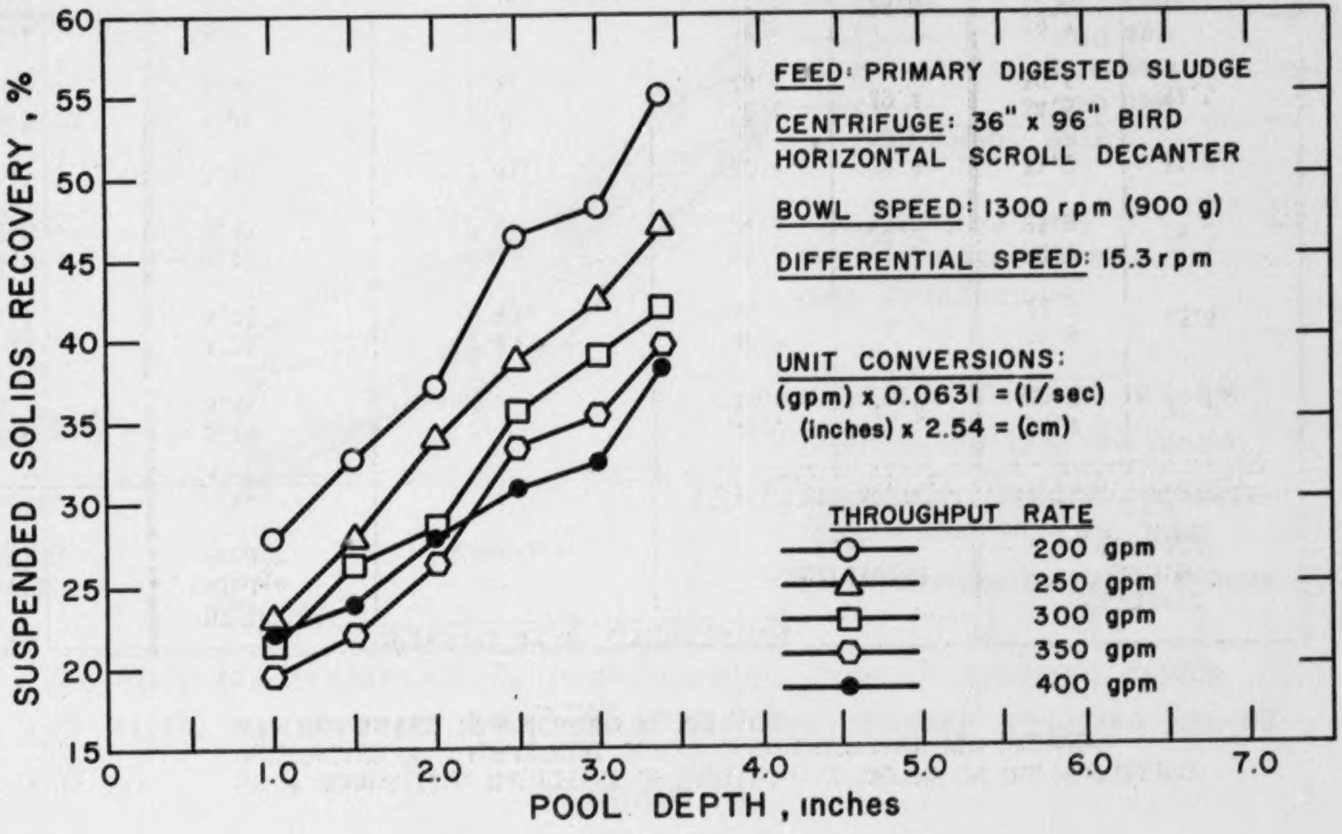
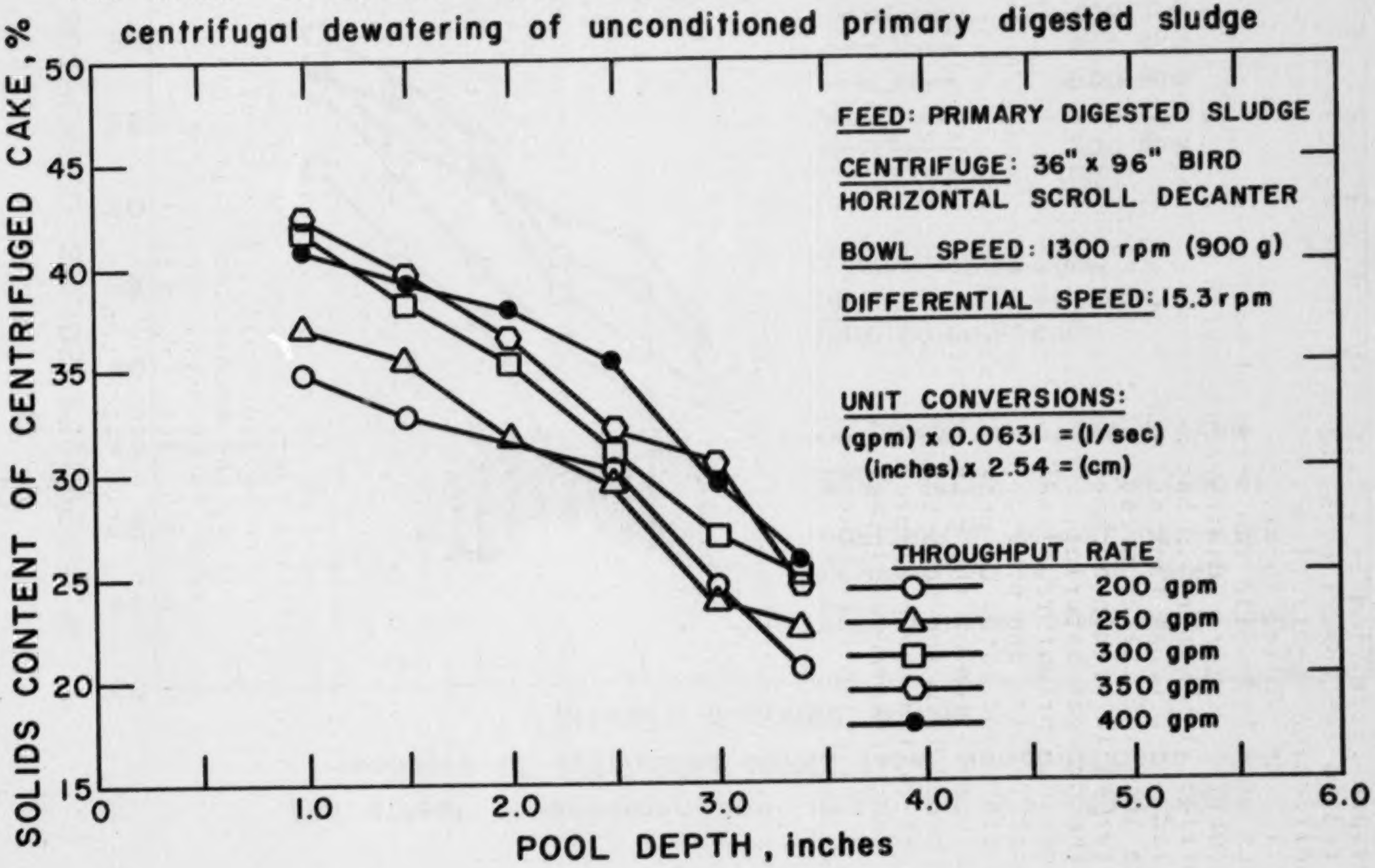


FIGURE 16

The effect of decanter pool depth on cake dryness obtained during centrifugal dewatering of unconditioned primary digested sludge



For any particular pool depth, decreasing solids recovery and increasing cake dryness were generally experienced as the sludge feedrate was increased within the range investigated. The comparative reversed trends of Figures 15 and 16 as well as the display of a somewhat linear family of curves in each suggested that cake quality was a function of suspended solids recovery. This proved to be the case as is demonstrated by the plot of these data shown in Figure 17. The dependency is seen to be a linear one. Also, the phenomena is understandable since the experienced incremental increases in suspended solids captures consisted, for the most part, of finely suspended material containing a proportionally larger amount of surface bound water per unit of particle mass.

In the absence of any conditioning of the JWPCP primary digested sludge, the results depicted in Figure 17 define the absolute performance (under conditions of little or no wear) of the Bird horizontal scroll centrifuge. Mathematically, this performance is defined by the corresponding linear equation

$$R = -(1.41)C + 78.4 \text{ , with } (20 < C > 42)$$

where R = percent solids capture, %
C = dry weight percentage of cake solids, %

A typical base performance curve demonstrating the capabilities of the test centrifuge under a fixed set of operating conditions is presented in Figure 18. Such performance curves for the other investigated sludge feedrates, or for that matter, any feedrate would take on a similar format as this one shown. From an operational standpoint, use of such curves would enable centrifuge operating conditions to be set up on the basis of a desired result.

In an attempt to further increase the solids capture in the Bird horizontal scroll centrifuge, polymer addition to the primary digested sludge feed was investigated. A number of commercially available cationic polymers were tested. All tests were conducted with the sludge feed, bowl speed, differential speed and pool depth held constant at 250 gpm (15.8 l/sec), 1300 rpm, 15.3 rpm and 3.4 inches (8.6 cm), respectively. Only chemical dosage was allowed to vary.

FIGURE 17

Dewaterability of unconditioned primary digested sludge in a 36" x 96" Bird horizontal scroll centrifuge

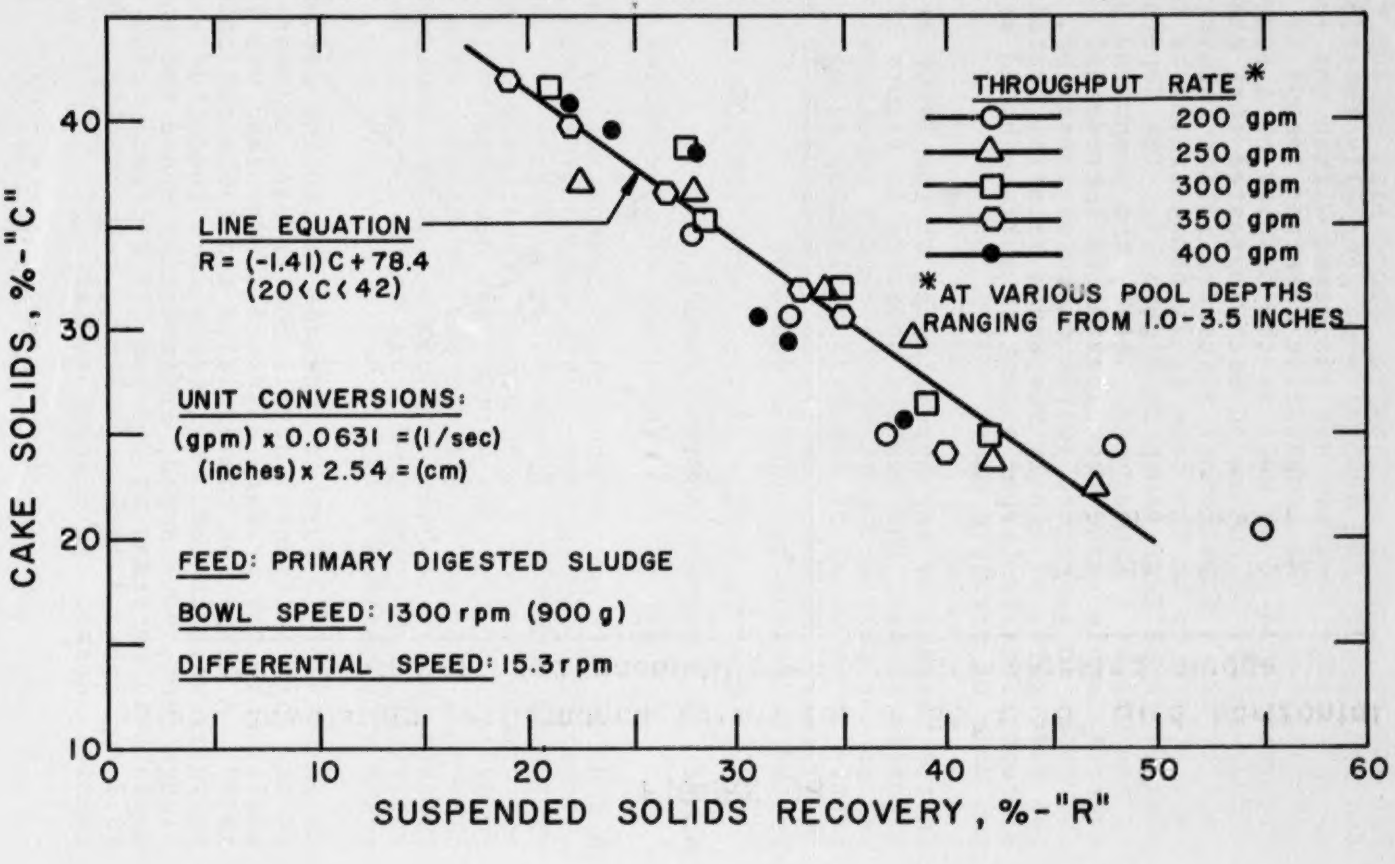
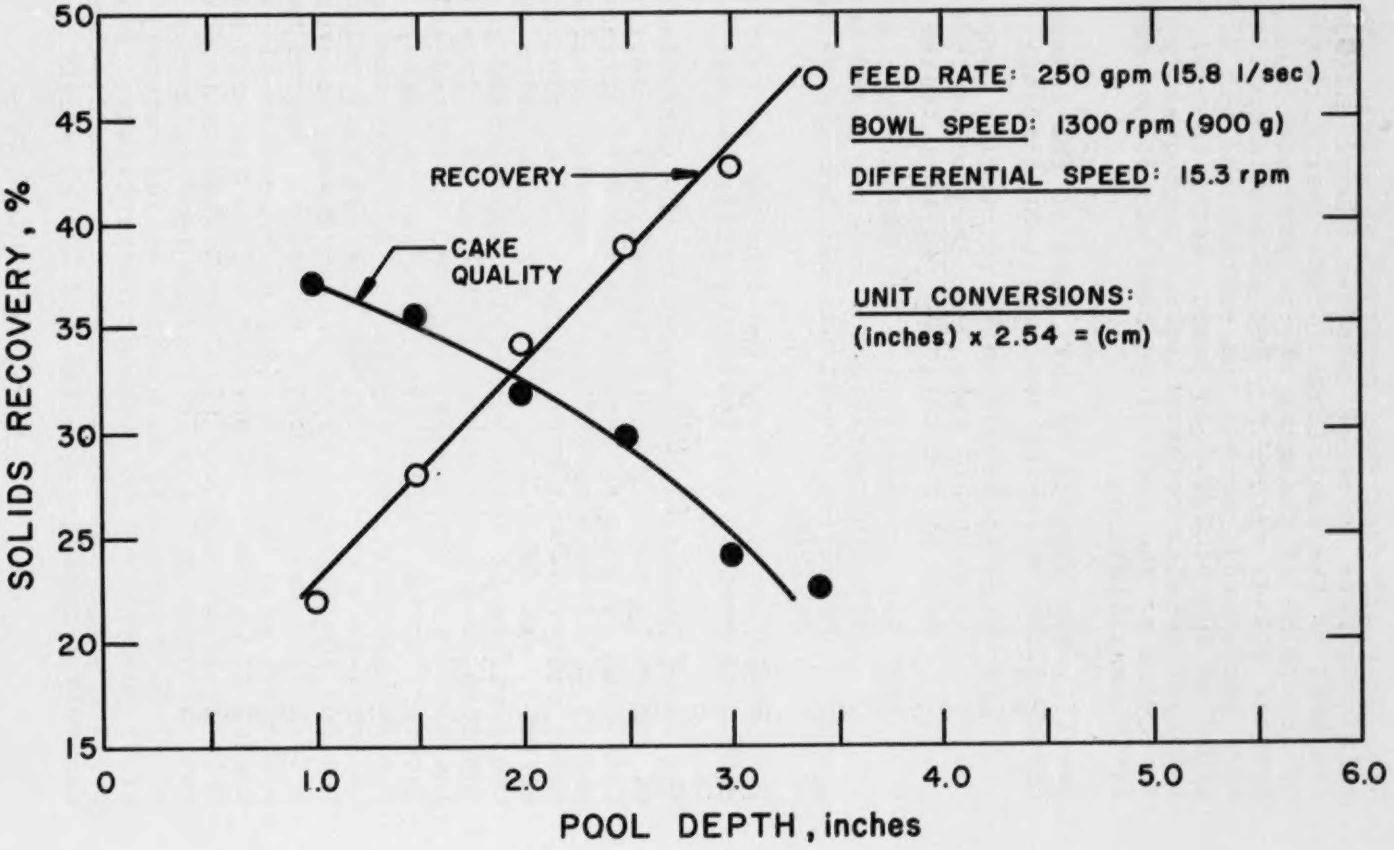


FIGURE 18

Typical dewatering performance curves for a 36" x 96" Bird horizontal scroll centrifuge fed unconditioned primary digested sludge



FEED RATE: 250 gpm (15.8 l/sec)
BOWL SPEED: 1300 rpm (900 g)
DIFFERENTIAL SPEED: 15.3 rpm

UNIT CONVERSIONS:
(inches) x 2.54 = (cm)

Regarding all test runs reported on herein, polymer solutions were injected into the sludge stream within the bowl of the centrifuge. Some test work was conducted to determine if changing the polymer addition point would enhance solids recovery. Two alternate injection points were considered, namely the suction and the discharge sides of the sludge feed pump; both, however, yielded inferior results comparatively. Consequently, polymer injection to the centrifuge bowl was deemed best for the JWPCP installation.

Overall, the results of this part of the investigation revealed the following two important findings.

(1) High suspended solid recoveries (approximately 95 percent) were sometimes obtainable with each of the cationic polymers tested.

(2) For any particular polymer product used, dewatering performance under a fixed set of operating conditions was not always reproducible.

It is important that these two findings be kept in mind when interpreting the following presented data.

The first finding is evidenced by the performance data of Tables 16 thru 18 which respectively summarize some trial-run dewatering results on the Bird horizontal scroll centrifuge as effected by varying dosages of three different cationic polymers (Nalco 610, Calgon WT-2570, and Hercofloc 810). For comparative purposes, the experienced solid recoveries are plotted as a function of polymer dosage in Figure 19: In all cases, increased polymer dosages effected increased solids recovery up to a point whereupon further dosage increases yielded no additional recovery. Although the recovered maximums were relatively the same for each polymer tested, the minimum "break point" dosage necessary to attain this result differed markedly. Approximately 5 lbs/ton (2.5 kg/metric ton) of Hercofloc 810 were needed to attain a 94 percent solids recovery maximum. This is to be compared with the 8 lbs/ton (4.0 kg/metric ton) of Nalco 610 and 10 lbs/ton (5.0 kg/metric ton) of WT-2570 necessary to achieve solids recovery maximums of 95 percent and 96 percent, respectively. During polymer usage, the solids content of the discharging cakes randomly ranged between 18% and 22% by weight.

Table 16: DATA* SUMMARIZING THE SLUDGE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE AS EFFECTED BY VARYING DOSAGES OF NALCO 610.

PARAMETERS

1. Sludge Feed Rate.................. 250 gpm (15.8 l/sec)
2. Bowl Speed........................ 1300 rpm
3. Differential Speed................ 15.3 rpm
4. Pool Depth........................ 3.4 inches (8.6 cm)
5. Flowrate from Chemical Station... 16 gpm (1.0 l/sec)

SUSPENDED SOLIDS CONCENTRATION			CHEMICAL DOSAGE	PERCENT RECOVERY OF SUSPENDED SOLIDS
Sludge Feed** -%-	Centrate -%-	Cake -%-	-lbs/ton-	-%-
3.92	2.55	23.3	0.0	34.6
3.68	1.75	18.5	1.1	54.7
3.70	1.33	18.4	2.2	66.7
3.72	0.94	19.5	3.2	76.7
3.57	0.17	18.6	9.0	95.9
3.89	0.17	19.5	9.3	96.3
2.96	0.15	16.0	13.5	95.6
2.71	0.13	16.4	17.7	95.7
2.39	0.12	15.8	18.4	95.6

* All data pertain to dewatering tests conducted on JWPCP primary digested sludge with a 36-inch x 96-inch horizontal scroll centrifuge.

** Reported values are corrected for dilution with 16 gpm (1.0 l/sec) of polymer solution from the chemical station.

Unit Conversions: (% Solids) x 10,000 = (mg/l)
(lbs/ton) x 0.5 = (kg/metric ton)

Table 17: DATA* SUMMARIZING THE SLUDGE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE AS EFFECTED BY VARYING DOSAGES OF WT-2570.

PARAMETERS
1. Sludge Feed Rate................ 250 gpm (15.8 l/sec)
2. Bowl Speed...................... 1300 rpm
3. Differential Speed.............. 15.3 rpm
4. Pool Depth...................... 3.4 inches (8.6 cm)
5. Flowrate from Chemical Station... 16 gpm (1.0 l/sec)

SUSPENDED SOLIDS CONCENTRATION			CHEMICAL DOSAGE	PERCENT RECOVERY OF SUSPENDED SOLIDS
Sludge Feed** -%-	Sludge Centrate -%-	Cake -%-	-lbs/ton-	-%-
3.96	2.49	27.6	0.0	36.5
3.71	2.11	20.4	1.1	44.1
3.61	1.51	18.7	2.2	60.3
3.76	1.40	18.9	3.2	65.2
3.68	0.91	18.4	4.4	77.6
4.19	0.60	22.2	6.5	87.1
3.65	0.33	23.6	8.8	91.7
3.57	0.17	19.5	10.1	95.7
3.80	0.16	20.8	10.5	96.3
3.87	0.15	20.2	11.4	96.5
3.85	0.17	20.2	12.5	96.2

* All data pertain to dewatering tests conducted on JWPCP primary digested sludge with a 36-inch x 96-inch horizontal scroll centrifuge.

** Reported values are corrected for dilution with 16 gpm (1.0 l/sec) of polymer solution from the chemical station.

Unit Conversions: (% Solids) x 10,000 = (mg/l)
(lbs/ton) x 0.5 = (kg/metric ton)

Table 18: DATA* SUMMARIZING THE SLUDGE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE AS EFFECTED BY VARYING DOSAGES OF HERCOFLOC 810--Run No. 1

PARAMETERS
1. Sludge Feed Rate................ 250 gpm (15.8 l/sec)
2. Bowl Speed....................... 1300 rpm
3. Differential Speed............... 15.3 rpm
4. Pool Depth....................... 3.4 inches (8.6 cm)
5. Flowrate from Chemical Station... 16 gpm (1.0 l/sec)

SUSPENDED SOLIDS CONCENTRATION			CHEMICAL DOSAGE	PERCENT RECOVERY OF SUSPENDED SOLIDS
Sludge Feed** -%-	Centrate -%-	Cake -%-	-lbs/ton-	-%-
3.68	2.16	23.9	0.0	41.2
3.69	1.43	19.0	1.1	63.5
3.62	0.93	18.8	2.2	76.4
3.65	0.49	19.4	3.3	86.1
3.61	0.28	19.0	4.4	93.1
3.55	0.25	20.4	5.7	93.8
3.43	0.25	20.1	7.1	93.3
3.80	0.25	21.4	7.2	94.0
3.77	0.22	19.9	8.5	94.7
3.81	0.28	21.0	9.5	93.6
3.69	0.27	20.2	10.9	93.6
3.77	0.26	20.6	11.7	93.8
3.78	0.23	22.5	12.7	94.5

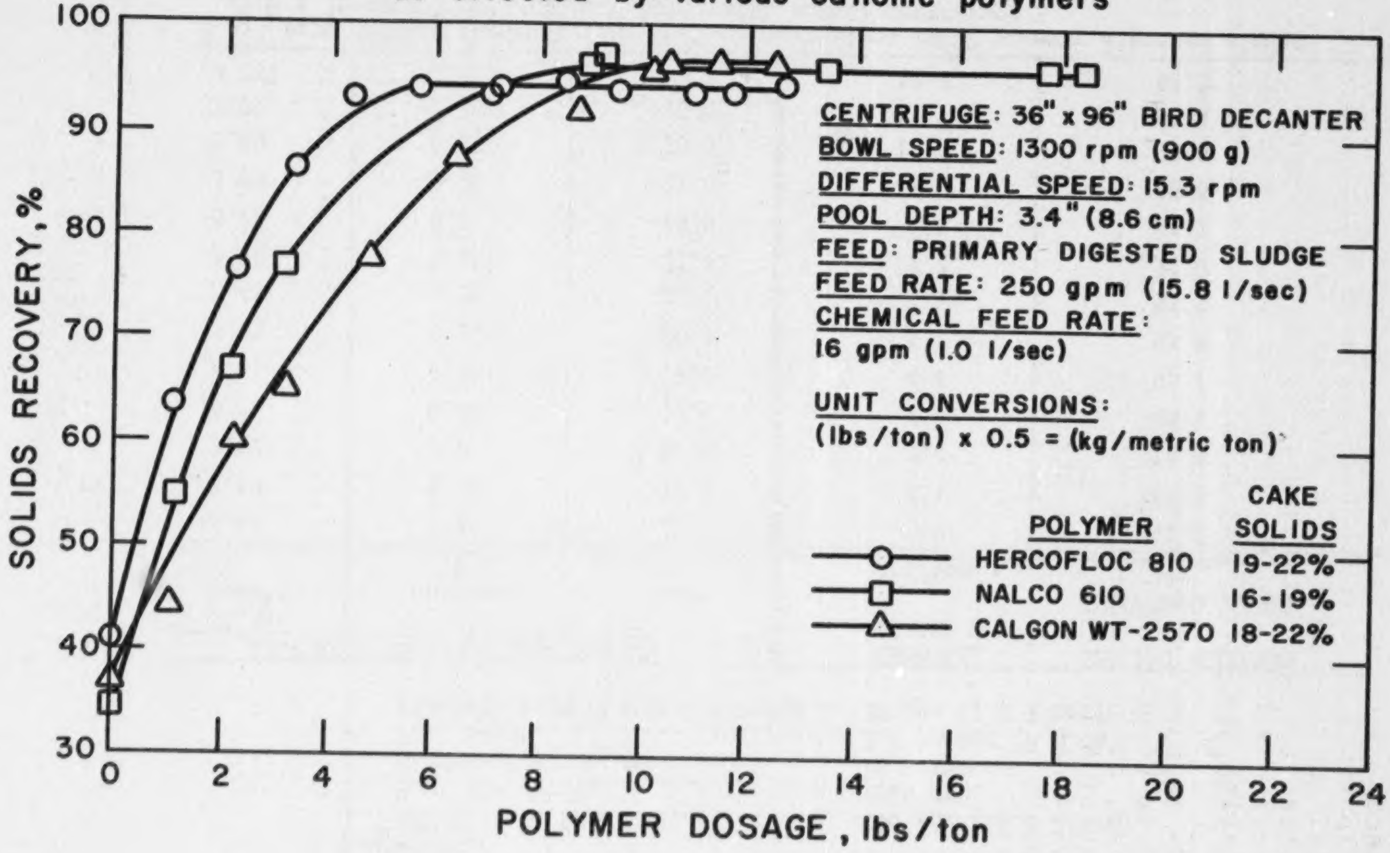
* All data pertain to dewatering tests conducted on JWPCP primary digested sludge with a 36-inch x 96-inch Bird horizontal scroll centrifuge.

** Reported values are corrected for dilution with 16 gpm (1.0 l/sec) of polymer solution from the chemical station.

Unit Conversions: (% Solids) x 10,000 = (mg/l)
(lbs/ton) x 0.5 = (kg/metric ton)

FIGURE 19

Horizontal scroll centrifuge: sludge dewatering performance as effected by various cationic polymers



The second finding is evidenced by a comparison of the data in Table 18 with that in Table 19 obtained from a trial run conducted on a different day but under identical test conditions with the same polymer (Hercofloc 810). The solids recovery data from these two tables are plotted as a function of polymer dosage in Figure 20. As noted, only 86 percent suspended solids capture was possible in the latter run as compared to 94 percent in the former. Both occurred, however, at approximately the same "break point" dosage of 5 lbs/ton (2.5 kg/metric ton). Since similar recovery differences were observed with several of the polymer products tested and because a thorough check revealed the absence of any problem with the chemical distributing or centrifuge systems, it could only be surmised that the anomaly was the result of some ever changing quantitative or qualitative characteristic of the sludge feed material which interfered with and partially negated the polymer's activity.

Regarding other cationic polymer products tested (Dow C-41, Calgon WT-2580, Hercofloc 814-X and Magnifloc 560-C), the "break point" dosages required of each to achieve maximum solids capture ranged from 5 to 14 lbs/ton (2.5 to 7.0 kg/metric ton). For the most part, the solids content of discharging cakes ranged between 18% and 22% by weight. Dilution of batched polymer solutions to something less than 0.5% (5000 mg/l) prior to injection into the sludge stream did nothing to enhance suspended solid recoveries.

The centrifugal dewaterability of optimally heat-conditioned digested sludge was carried out in the following manner. First, efforts were applied towards centrifuging unthickened portrate both with and without cationic polymer addition. Followup work was then similarly conducted on thickened portrate underflow from the picket thickening clarifier. A flowsheet schematic of each of the two described systems is presented in Figures 21 and 22. As noted, each system was set up to provide for optional polymer injection into the centrifuge bowl. Only one cationic polymer was used for this work, namely Hercofloc 810.

Held constant throughout this phase of the test program were the heat conditioning variables. Digested sludge was cooked for 40 minutes at 350°F (175°C) in the Porteous pilot plant unit. Discharged portrate was

Table 19: DATA* SUMMARIZING THE SLUDGE DEWATERING PERFORMANCE OF A HORIZONTAL SCROLL CENTRIFUGE AS EFFECTED BY VARYING DOSAGES OF HERCOFLOC 810--Run No. 2

PARAMETERS
1. Sludge Feed Rate................. 250 gpm (15.8 1/sec)
2. Bowl Speed....................... 1300 rpm
3. Differential Speed............... 15.3 rpm
4. Pool Depth....................... 3.4 inches (8.6 cm)
5. Flowrate from Chemical Station... 16 gpm (1.0 1/sec)

SUSPENDED SOLIDS CONCENTRATION			CHEMICAL DOSAGE	PERCENT RECOVERY OF SUSPENDED SOLIDS
Sludge Feed** -%-	Centrate -%-	Cake -%-	-lbs/ton-	-%-
3.42	1.95	21.6	0.0	43.1
3.40	1.31	17.8	1.2	65.0
3.38	0.75	17.2	3.5	79.8
3.52	0.59	18.6	6.9	85.0
3.56	0.50	17.9	7.7	87.5
3.45	0.54	18.1	10.5	86.0
3.39	0.56	18.4	11.8	85.0
3.35	0.45	19.3	13.2	87.7

*All data pertain to dewatering tests conducted on JWPCP primary digested sludge with a 36-inch x 96-inch horizontal scroll centrifuge.

**Reported values are corrected for dilution with 16 gpm (1.0 1/sec) of polymer solution from the chemical station.

Unit Conversions: (% Solids) x 10,000 = (mg/1)
(1bs/ton) x 0.5 = (kg/metric ton)

FIGURE 20

Horizontal scroll centrifuge: erratic sludge dewatering performance obtained with polymer usage

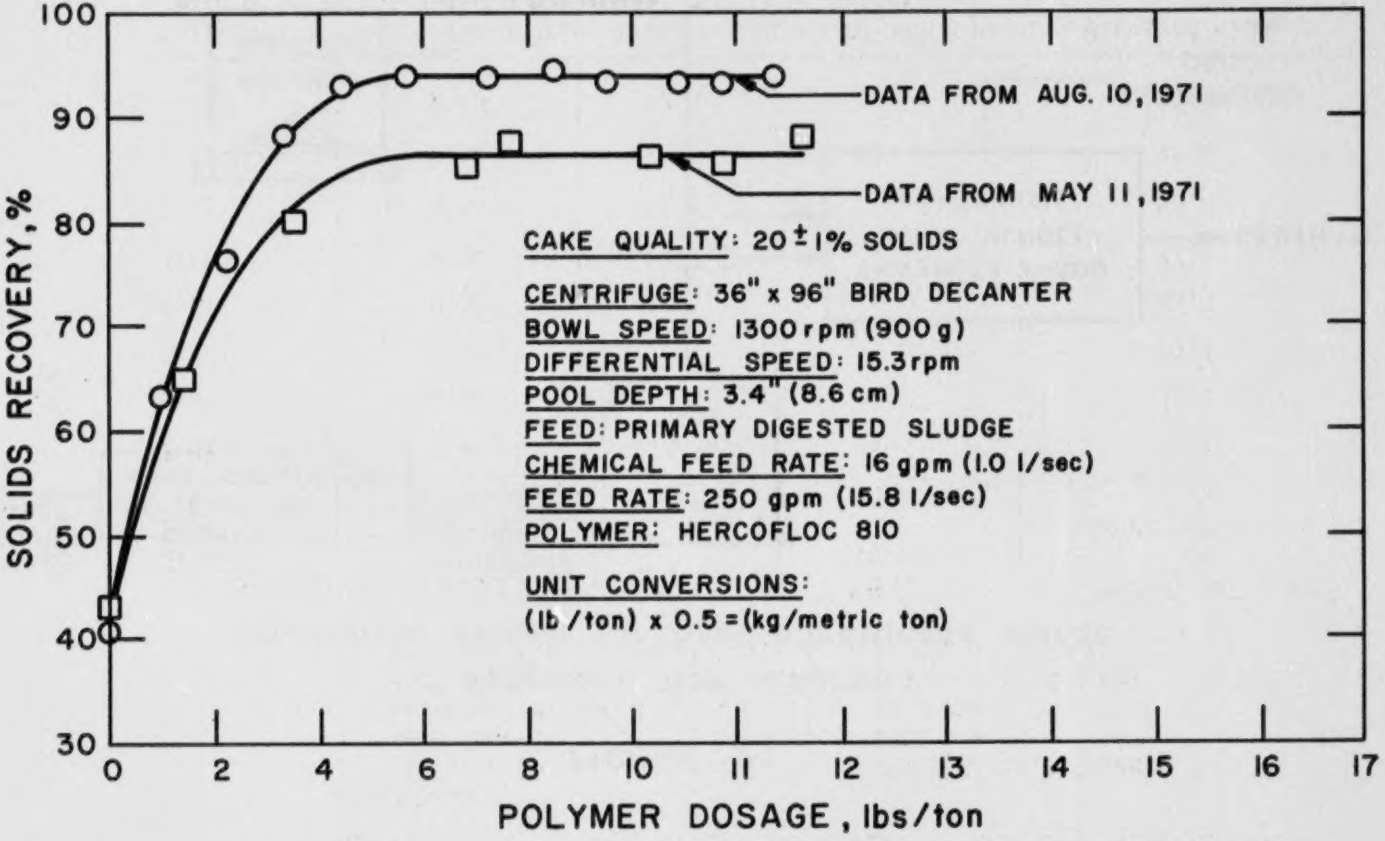


FIGURE 21

Schematic flow diagram
Dewatering system for heat conditioned sludge

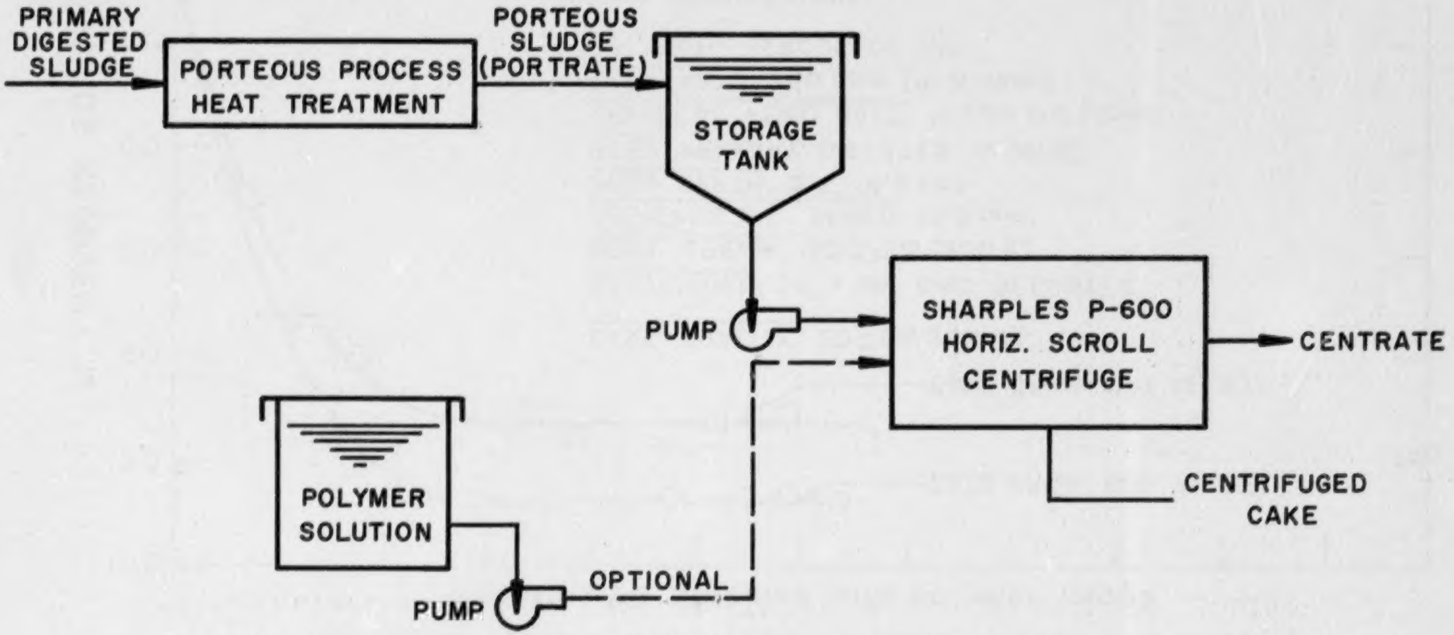
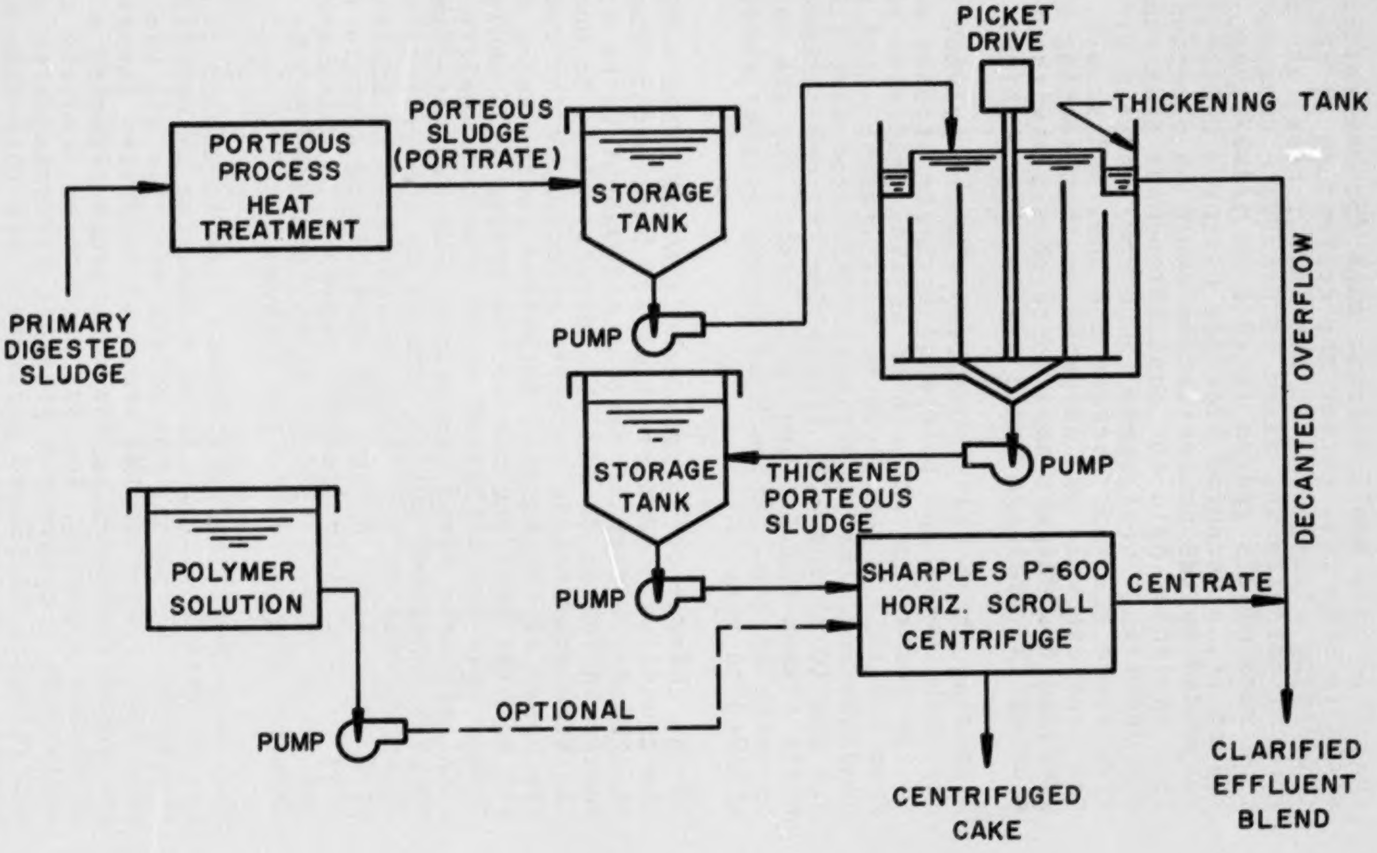

PRIMARY DIGESTED SLUDGE
PORTEOUS PROCESS HEAT TREATMENT
PORTEOUS SLUDGE (PORTRATE)
STORAGE TANK
PUMP
SHARPLES P-600 HORIZ. SCROLL CENTRIFUGE
CENTRATE
CENTRIFUGED CAKE
POLYMER SOLUTION
PUMP
OPTIONAL

FIGURE 22

Schematic flow diagram
Dewatering systems for thickened heat-conditioned sludge



collected in a small storage tank for controlled steady-state feeding into either the centrifuge or the picket thickening clarifier. In the latter case, the administration of portrate was fixed to provide a continuous overflow rate of 225 gpd/sq ft (9.2 cu m/day/sq m). From Figure 14, a decanted overflow having a 0.37% (3700 mg/l) suspended solids concentration would be expected. Other test variables held constant throughout this study were the centrifuge bowl speed (5000 rpm) and the differential speed (12 rpm) between the bowl and scroll. Also, the centrate weir was adjusted to that setting which provided the deepest pool depth possible without overflowing the drainage beach area of the machine.

Regarding those tests conducted without polymer addition, the unthickened and thickened portrate streams were fed to the centrifuge at each of several feedrates ranging from 1.2 to 3.4 gpm (0.08 to 0.21 l/sec). With polymer conditioning, the investigated feedrates were 1.2 and 3.4 gpm (0.08 and 0.21 l/sec) for the unthickened portrate stream and 3.4 gpm (0.21 l/sec) for the thickened portrate stream. At each of these, polymer dosage was allowed to vary.

In the absence of polymer conditioning, data summarizing the centrifugal dewaterability of both unthickened and thickened portrate at various throughput rates are presented in Tables 20 and 21, respectively. In both tables, the tabulated solids recovery effected by the centrifuge are based on the initial suspended solids being fed to the machine only and not to the system as a whole. Additional data are tabulated which show the quality of the final effluent blend (decantate plus centrate) and the overall suspended solids removal by the system, i.e. removal by thermal volatization, elimination by thermal transfer to the dissolved phase, and centrifugal capture in the cake. These latter removal values were calculated on the basis of 3.5% (35,000 mg/l) suspended solids in the digested sludge fed to the system.

The centrifugal solids capture data in Tables 20 and 21 are plotted in Figure 23 as a function of centrifuge feedrate. As noted, the effect was, for all practical purposes, linear in the range of feedrates investigated. Increased feedrates to the centrifuge effected a decrease in solids capture. For any particular feedrate to the centrifuge, capture was greatest percentagewise when centrifuging thickened portrate. For this same material, however, centrate quality was poorest. Nevertheless,

Table 20: DATA* SUMMARIZING THE DEWATERABILITY OF UNTHICKENED HEAT-CONDITIONED DIGESTED SLUDGE BY HORIZONTAL SCROLL CENTRIFUGATION

PARAMETERS

1. Processed Material:...... JWPCP Primary Digested Sludge
2. Porteous Conditioning:... 40 min @ 350°F (175°C)
3. Centrifuge:.............. Sharples P-600 solid bowl decanter
4. Bowl Speed:.............. 5000 rpm
5. Differential Speed:...... 12 rpm
6. Pool Depth:.............. maximum possible

CENTRIFUGE FEEDRATE -gpm-	SUSPENDED SOLIDS CONCENTRATIONS Unthickened Portrate Feed -%-	Centrate -%-	Cake -%-	SUSPENDED SOLIDS CAPTURE IN CENTRIFUGE -%-	TOTAL SUSPENDED SOLIDS REMOVAL BY SYSTEM** -%-
1.2	2.68	0.74	32.3	74.1	80.7
1.5	2.47	0.73	31.5	72.1	81.0
2.0	2.41	0.86	33.1	66.0	77.4
2.5	2.53	1.01	32.6	62.0	73.4
3.0	2.57	1.11	35.7	58.6	70.5
3.4	2.24	1.01	31.3	56.7	73.5

* All data pertain to tests conducted with JWPCP primary digested sludge.

** Removal by "System" includes centrifugal capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values are based on a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions: (gpm) x 0.0631 = (l/sec)
(% Solids) x 10,000 = (mg/l)

Table 21: DATA* SUMMARIZING THE DEWATERABILITY OF THICKENED HEAT-CONDITIONED DIGESTED SLUDGE BY HORIZONTAL SCROLL CENTRIFUGATION

PARAMETERS:

1. Processed Material:........ JWPCP primary digested sludge
2. Porteous Conditioning:..... 40 min @ 350°F (175°C)
3. Thickener Overflow Rate:... 225 gpd/sq ft (9.2 cu m/day/sq m)
4. Centrifuge:................ Sharples P-600 horizontal scroll centrifuge
5. Bowl Speed:................ 5000 rpm
6. Differential Speed:........ 12 rpm
7. Pool Depth:................ maximum possible

CENTRIFUGE FEEDRATE -gpm-	SUSPENDED SOLIDS CONCENTRATION			SUSPENDED SOLIDS CAPTURE IN CENTRIFUGE -%-	SUSPENDED SOLIDS IN EFFLUENT BLEND (Decantate+Centrate) -%-	TOTAL SUSPENDED SOLIDS REMOVAL BY SYSTEM** -%-
	Unthickened Portrate Feed -%-	Centrate -%-	Cake -%-			
1.2	11.27	3.32	24.9	81.4	0.61	84.7
2.0	11.08	4.13	25.8	74.7	0.69	82.5
3.0	8.08	3.55	28.5	64.1	0.70	82.0

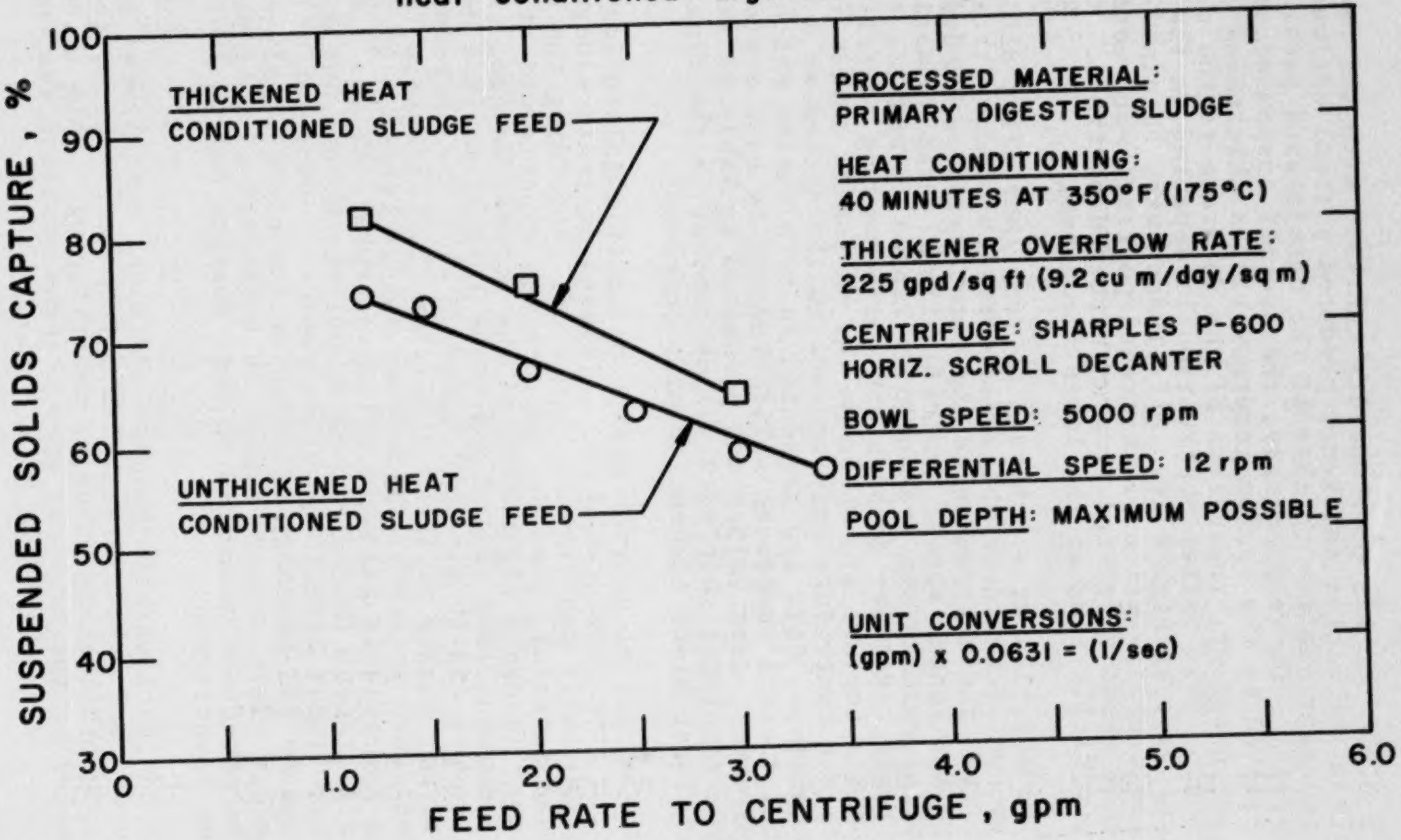
* All data pertain to test conducted on JWPCP primary digested sludge.

** Removal by "System" includes centrifugal capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values are based on a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions: (gpm) x 0.0631 = (l/sec)
(% Solids) x 10,000 = (mg/l)

FIGURE 23

The effect of feed rate on the centrifugal capture of suspended solids from unthickened and thickened heat-conditioned digested sludge



a blend of this poor quality centrate with the decantate from the picket thickener produced a final effluent of superior quality to that of the unthickened portrate system. Correspondingly, the overall suspended solids removed by the system incorporating a thickening step was greatest, regardless of the feedrate to the centrifuge. This latter observation is depicted in the graphical plot of Figure 24. All sludge cakes obtained from the centrifugation of thickened portrate were wetter than those generated from unthickened portrate. This was especially true at the lower feedrates.

The addition of a cationic polymer (Hercofloc 810) to the unthickened or thickened portrate sludge streams within the bowl enhanced the recovery of suspended solids by horizontal scroll centrifugation. Data summarizing these results are presented in Tables 22 and 23, respectively. Polymer dosages and corresponding centrifugal solids capture are based on the suspended solids fed to the centrifuge only and not to the system as a whole. Additional data are presented in both tables which show the overall suspended solids removal by each system. Moreover, data values are presented in Table 23 showing the resulting suspended solids content in the final effluent blend (decantate plus centrate).

The effect of polymer dosage on centrifugal solids capture from unthickened and thickened portrate sludge is graphically depicted in Figure 25. Regarding the unthickened material, greatest capture was experienced at the lower feedrate regardless of the polymer dosage. At a throughput rate of 1.2 gpm (0.08 l/sec), maximum solids recovery (88-89 percent) occurred at a "break point" polymer dosage of about 4 lbs/ton (2.0 kg/metric ton). Continued increases in polymer dosage beyond this yielded no appreciable gains in solids capture. At the 3.4 gpm (0.21 l/sec) throughput rate, polymer dosage had a somewhat linear effect on solids capture. Greatest solids capture (83 percent) occurred at the highest polymer dosage administered, namely 10.6 lbs/ton (5.3 kg/metric ton). The effect of increased polymer dosages beyond this were not investigated.

In conjunction with polymer addition, centrifugal captures were enhanced with the incorporation of Porteous sludge thickening prior to centrifuging. This is evidenced by the vertical displacement of those two curves

FIGURE 24

Suspended solids removal by heat conditioning, optional thickening and dewatering by horizontal scroll centrifugation

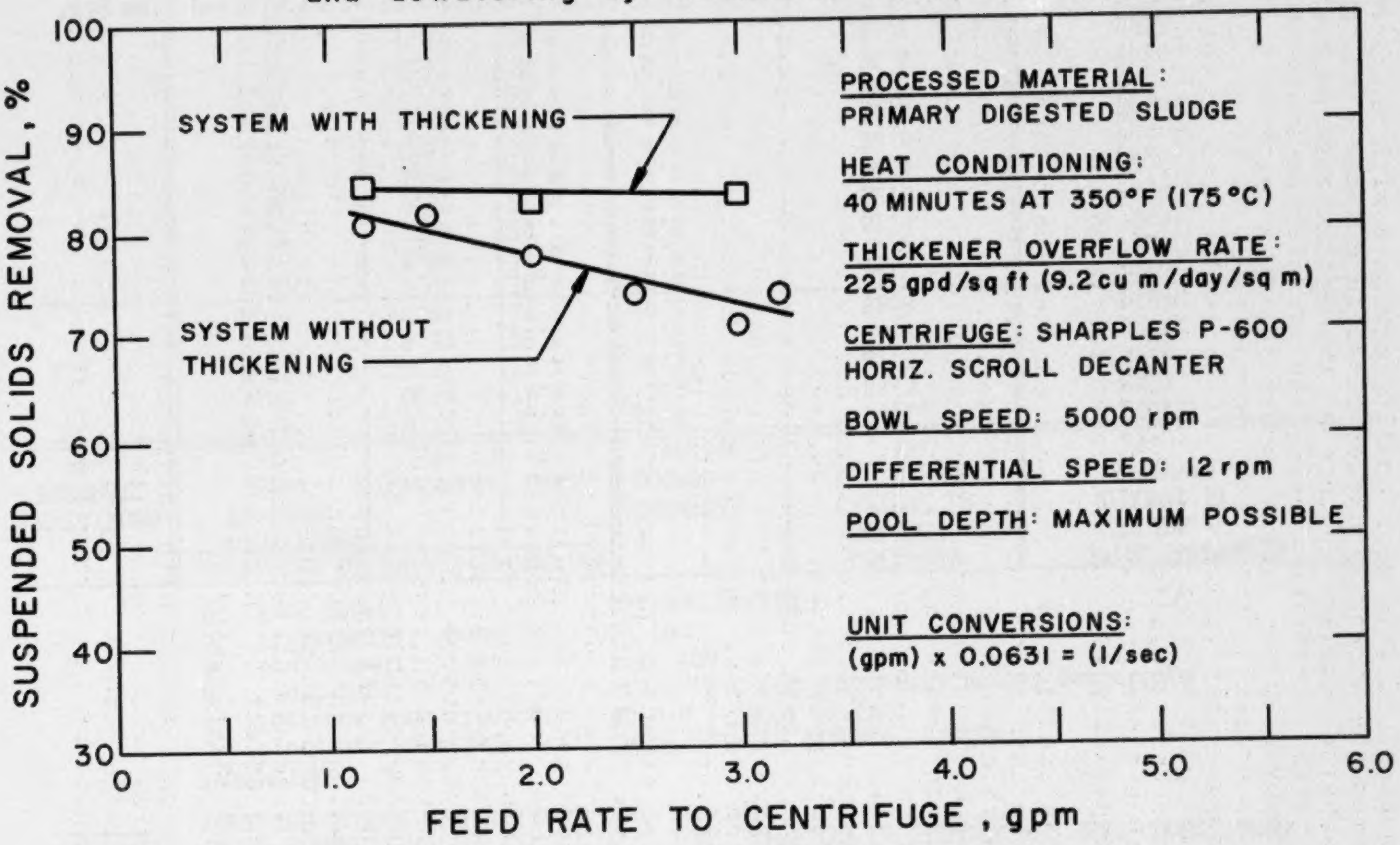


Table 22: DATA* SUMMARIZING THE CENTRIFUGAL DEWATERABILITY OF UNTHICKENED HEAT-CONDITIONED DIGESTED SLUDGE WITH POLYMER CONDITIONING.

PARAMETERS
1. Processed Material:...... JWPCP primary digested sludge
2. Porteous Conditioning:... 40 min @ 350°F (175°C)
3. Centrifuge:.............. Sharples P-600 horizontal scroll centrifuge
4. Bowl Speed:.............. 5000 rpm
5. Differential Speed:...... 12 rpm
6. Pool Depth:.............. maximum possible

CENTRIFUGE FEEDRATE -%-	SUSPENDED SOLIDS CONCENTRATION Unthickened Portrate Feed -%-	Centrate -%-	Cake -%-	CHEMICAL DOSAGE -lbs/ton-	SUSPENDED SOLIDS CAPTURE IN CENTRIFUGE -%-	TOTAL SUSPENDED SOLIDS REMOVAL BY SYSTEM** -%-
1.2	2.68	0.74	32.3	0.0	74.1	80.7
	3.00	0.38	31.5	3.4	88.3	90.2
	2.33	0.32	28.2	6.5	87.3	91.9
	2.40	0.29	29.5	7.5	88.8	92.6
	2.36	0.34	27.1	9.2	86.8	91.4
3.4	2.13	1.05	30.4	0.0	52.6	72.5
	2.13	0.84	28.6	1.7	62.2	78.3
	2.07	0.84	29.2	2.6	61.3	78.3
	2.05	0.80	27.6	3.2	62.5	79.4
	2.03	0.76	26.4	3.9	64.6	80.6
	2.07	0.61	26.8	4.6	72.0	84.5
	1.94	0.61	25.1	6.0	70.3	84.6
	2.01	0.53	27.7	7.0	75.1	86.5
	1.90	0.41	28.0	9.3	79.4	89.6
	2.15	0.39	28.9	10.6	83.2	90.1

*All data pertain to tests conducted with JWPCP primary digested sludge.

**Removal by "System" includes centrifugal capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values assume a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions:
(gpm) x 0.0631 = (1/sec)
(lbs/ton) x 0.5 = (kg/metric ton)
(% Solids) x 10,000 = (mg/1)

Table 23: DATA* SUMMARIZING THE CENTRIFUGAL DEWATERABILITY OF THICKENED HEAT-CONDITIONED DIGESTED SLUDGE WITH POLYMER CONDITIONING.

PARAMETERS
1. Processed Material:........ JWPCP primary digested sludge
2. Porteous Conditioning:..... 40 min @ 350°F (175°C)
3. Thickener Overflow Rate:... 225 gpd/sq ft (9.2 cu m/day/sq m)
4. Centrifuge:................ Sharples P-600 horizontal scroll centrifuge
5. Bowl Speed:................ 5000 rpm
6. Differential Speed:........ 12 rpm
7. Pool Depth:................ maximum possible

CENTRIFUGE FEEDRATE -%-	SUSPENDED SOLIDS CONCENTRATION			CHEMICAL DOSAGE -lbs/ton-	SUSPENDED SOLIDS CAPTURE IN CENTRIFUGE -%-	SUSPENDED SOLIDS IN EFFLUENT BLEND (Decantate+Centrate) -%-	TOTAL SUSPENDED SOLIDS REMOVAL BY SYSTEM -%-
	Thickened Portrate Feed -%-	Centrate -%-	Cake -%-				
1.2	11.27	3.32	24.9	0.0	81.4	0.61	84.7
	8.01	0.29	24.5	3.2	97.5	0.36	91.0
	9.28	0.23	24.9	4.1	98.4	0.36	91.0
	9.10	0.15	24.6	6.9	99.0	0.35	91.3
	4.65	0.12	26.8	13.5	97.8	0.34	91.4

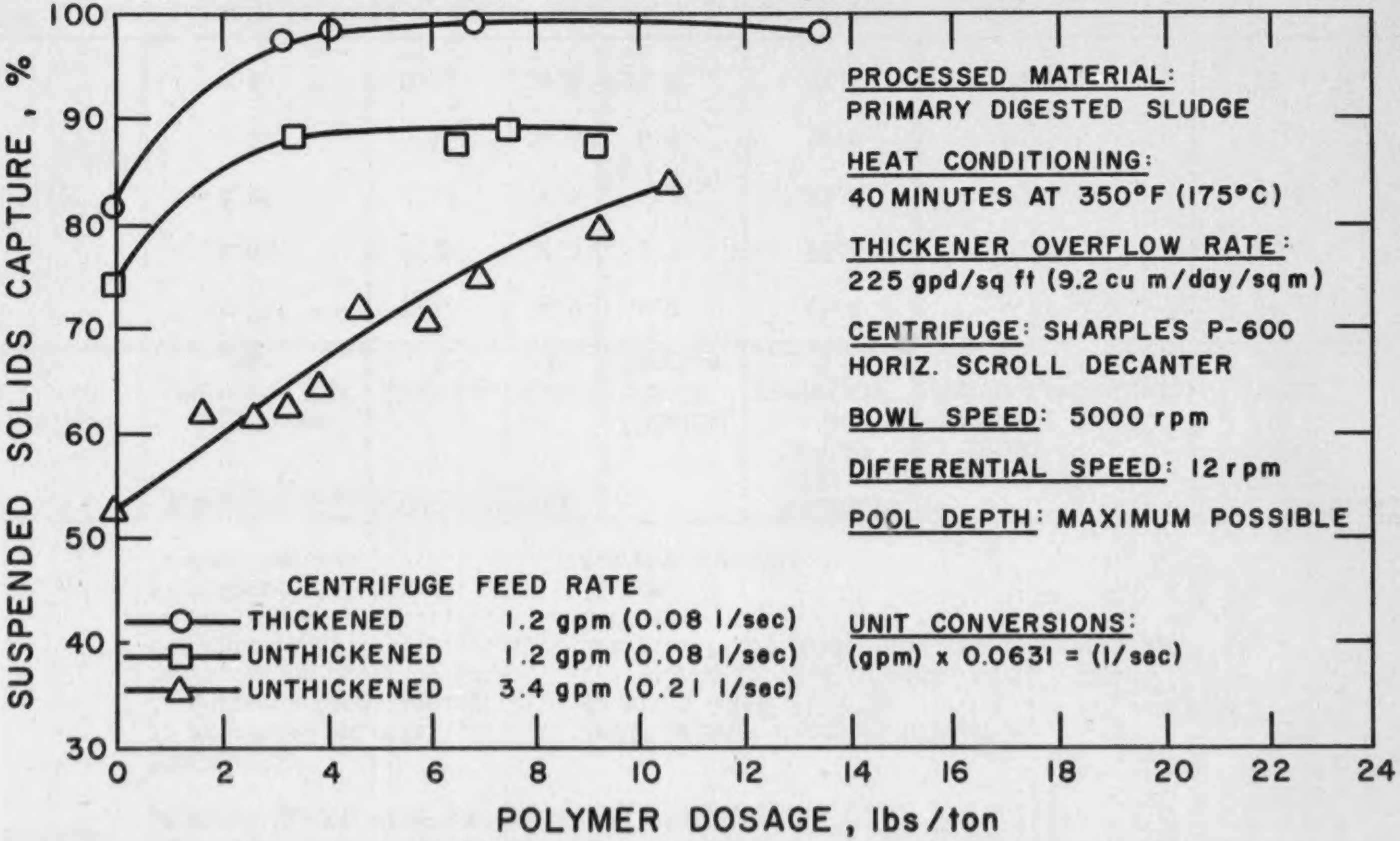
* All data pertain to tests conducted with JWPCP primary digested sludge.

** Removal by "System" includes centrifugal capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values assume a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions:
(gpm) x 0.0631 = (1/sec)
(lbs/ton) x 0.5 = (kg/metric ton)
(% Solids) x 10,000 = (mg/1)

FIGURE 25

The effect of polymer dosage on the centrifugal capture of suspended solids from unthickened and thickened heat-conditioned digested sludge



in Figure 25 which reflect the performances obtained at the 1.2-gpm (0.08-l/sec) throughput rate. Regarding the thickened material, maximum solids capture (98-99 percent) occurred at a "break point" polymer dosage of about 4 lbs/ton (2.0 kg/metric ton). Further polymer dosage increases yielded no additional recovery gains. The resulting centrates were superior to those obtained from centrifuging unthickened portrate. But considering a blend of this centrate with the decantate from the thickener, the overall suspended solids load in the effluents from both systems would be about the same, i.e. approximately 0.36% (3600 mg/l). Based on 3.5% (35,000 mg/l) suspended solids in digested sludge fed to either system, an overall suspended solids removal of about 91 percent would be experienced, at best, with the incorporation of a secondary polymer conditioning step and low centrifuge throughput rates.

Considering that a polymer solution was being injected into each system, cake qualities were better than expected. When thickening was employed, cake dryness remained relatively constant at about 24-25% solids by weight. Without the intermediate thickening step, generated cakes were greater than 26% solids by weight. This is to be compared with the 20% cakes obtained from previously discussed experiments using polymers in the isolated Bird test centrifuge at the JWPCP. Evidently, the heat conditioning step enhances cake dryness in a centrifugal dewatering operation incorporating polymers.

BASKET CENTRIFUGATION

Basket centrifuge test work was limited to an assessment of its potential for dewatering 'Bird' centrate in the second stage mode. The existing Bird centrifuge station was operated in its normal manner, i.e. with about 30 percent suspended solids removal from the incoming digested sludge stream. Followup centrifuge work with the 30- and 40-inch (76- and 102-cm) basket units was then conducted both with and without polymer conditioning of the Bird centrate feed stream. Throughout the testing, the rotational speeds of each unit were such that the generated radial acceleration was held constant at 1300 gravities.

Data from both piloted centrifuges were acquired in accordance with the following general sampling procedure.

During the course of a run, a grab sample of the feed material (Bird centrate) was taken. At different time intervals during the feed cycle grab samples of centrate were also taken. The feed cycle was terminated upon the acquisition of a centrate sample approximately one minute after the occurrence of break-through, i.e. the point at which centrate quality began to deteriorate. Centrate quality deterioration was both rapid and visually observable in runs incorporating polymer addition only. Without the use of polymers, the occurrence of breakthrough was quite unclear and was more or less determined by the experience of operation.

Cake samples were acquired in three different ways depending on which centrifuge was being evaluated and the type of data requiring generation. In the 30-inch (76-cm) unit, most of the accumulated solids were skimmed into a 55-gal. (208-liter) container and, after thorough mixing, sampled compositely; if an unskimmable heel remained in the basket, a composite of this material was also taken and weighted with the skimming sample to determine average cake dryness. Regarding most runs with the 40-inch (102-cm) unit, a small amount of the liquid-paste layer was skimmed off and discarded while the remaining solids were knifed out and sampled at one-inch (2.5-cm) intervals, thereby enabling an average cake dryness to be determined; in a few of the runs, however, the generated cakes were skimmed and sampled at one-inch (2.5-cm) intervals followed by separate sampling of any unskimmable heel. This latter procedure enabled solids build-up at intervals within the bowl to be assessed.

Tests with the 30-inch (76-cm) unit revealed that, without polymer usage, both solids recovery and cake quality were a function of the feedrate to the centrifuge. Data summarizing the base performance of the basket centrifuge for four different feedrates of Bird centrate are presented in Table 24. As noted, the total time of the feed cycle was decreased as the feedrate was increased. For each of these runs, the dependency of solids recovery on the duration of the feed cycle is graphically depicted in Figure 26 and is typical of a batch operation of this type. For any particular feedrate, the instantaneous solids recovery decreased with increased feed time. Also, instantaneous capture and, therefore, instantaneous centrate effluent quality decreased as throughput rate was increased. Even at the lowest 15-gpm (0.95 l/sec) feedrate tested, solid recoveries of only 82-84 percent were

Table 24: DATA* SUMMARIZING THE DEWATERING PERFORMANCE OF A BASKET CENTRIFUGE AT VARIOUS FEEDRATES.

PARAMETERS
1. Operation:....... 2nd stage mode
2. Feed Material:... Bird centrate (no conditioning)
3. Centrifuge:...... 30-inch (76-cm) Sharples basket centrifuge
4. Bowl Speed:...... 1750 rpm (1300 G's)

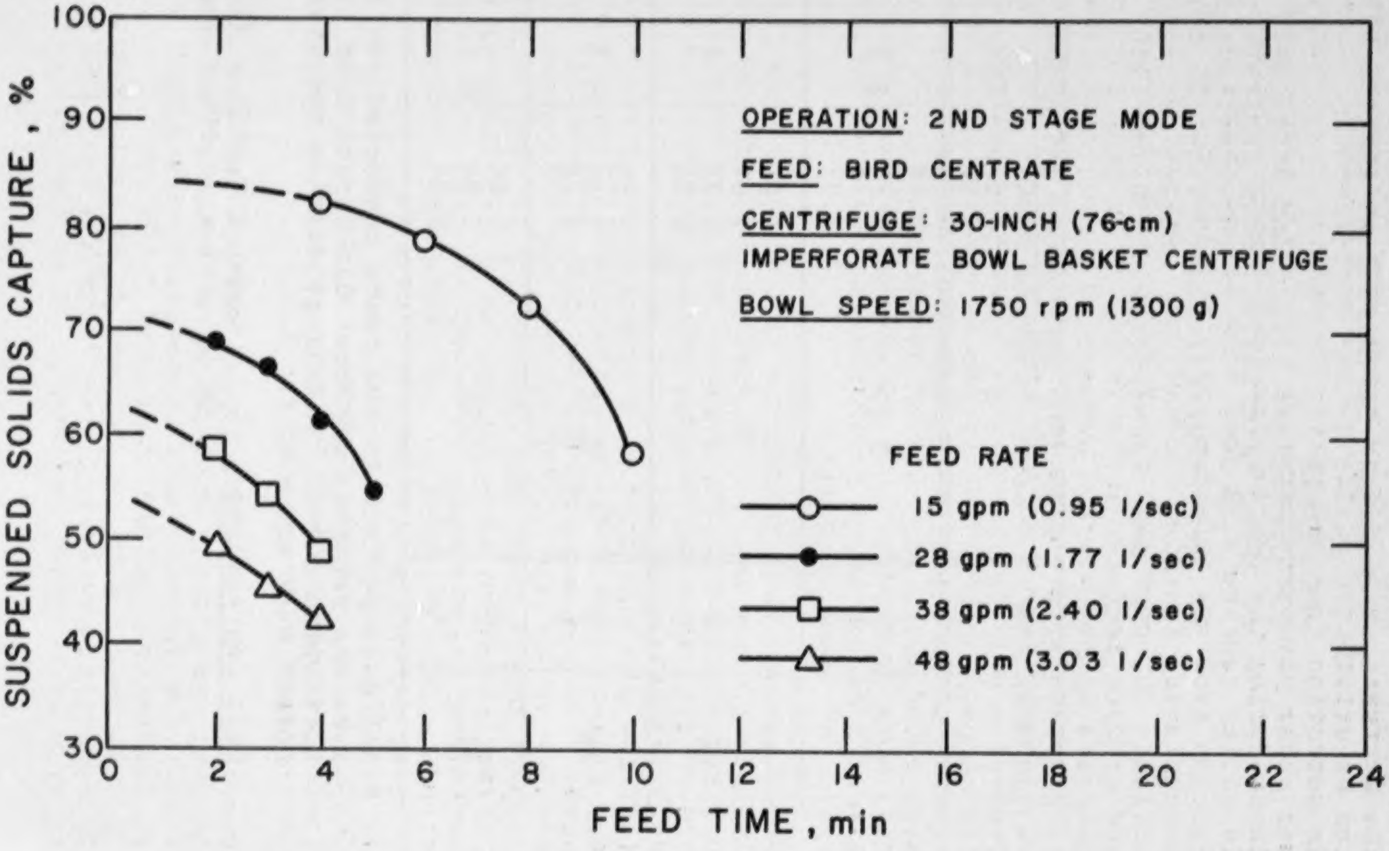
FEEDRATE -gpm-	FEED TIME -min-	SUSPENDED SOLIDS CONCENTRATION			SUSPENDED SOLIDS CAPTURE -%-
		'Bird' Centrate Feed -%-	Basket Centrate -%-	Cake -%-	
15	4	2.19	0.50	8.1	82.3
	6		0.59		78.8
	8		0.76		72.1
	10		1.07		58.9
28	2	2.63	1.00	9.8	69.0
	3		1.07		66.6
	4		1.22		61.2
	5		1.39		54.9
38	2	2.56	1.21	11.8	58.8
	3		1.32		54.5
	4		1.46		49.0
48	2	2.78	1.84	13.2	39.3
	3		1.94		35.4
	4		2.02		32.3

* All data pertain to the tests conducted on 'Bird centrate', i.e. the centrate effluent discharged from the existing horizontal scroll centrifuge station operating in its normal mode at JWPCP.

Unit Conversions:
(gpm) x 0.0631 = (l/sec)
(% Solids) x 10,000 = (mg/l)

FIGURE 26

Solids recovery in a basket centrifuge at different time intervals during feed cycles at various feed rates



obtainable during the first 4 minutes of the feed cycle. The decrease in solids recovery with increasing feedrate can be attributed partly to the corresponding decrease in detention time and partly to the increased turbulence and shear phenomena occuring within the moving liquid layer during the equilibrium feed-discharge phase. The loss in solids capture with feed time is indicative of their rejection from the quiescent settling zone due to solids accumulation therein. Indeed, the rapidity of this loss reflects the poor quality of the cakes discharged at the end of each feed cycle (Table 24). The effect of centrifuge feedrate on the average dryness of accumulated cake solids is graphically depicted in Figure 27. Cake dryness increased linearly from 8 to 13% solids by weight as the applied feedrates were increased from 15 to 48 gpm (0.94 to 3.03 l/sec). Wetter cakes can be attributed to the increased capture of finely suspended material containing more bound water per unit of particle mass. Evidently, this more than offset any additional dryness effected as a result of increased compaction time due to longer feed cycles at lower feedrates.

In an attempt to increase the solids capture in the 30-inch (76-cm) unit, some preliminary work incorporating polymer addition to the basket centrifuge was conducted. The results were encouraging enough to warrant a more detailed investigation of such in the larger 40-inch (102-cm) diameter unit. To simplify the evaluation, only one polymer (Dow C-41) was utilized for this phase of the work. The possibility of other polymer products doing a similar or perhaps better job was not discounted. With respect to all test runs reported on in this regard, polymer solutions were batched to a 0.1% (1000 mg/l) concentration and spray injected into the Bird centrate stream within the bowl of the centrifuge. Polymer injection at various points in the sludge feed line was looked at briefly; results, however, were significantly inferior. Consequently, polymer injection into the bowl of the basket was deemed best for this type of second stage centrifugation process at the JWPCP.

Overall, both suspended solids capture and generated cake quality was greatly enhanced as a result of polymer addition. The data in Table 25 summarize the effect of an equivalent dry polymer dosage of 4 lbs/ton (2.0 kg/metric ton) on the dewatering performance of the 40-inch (102-cm) basket centrifuge fed Bird centrate at each of several feedrates. As in the case of the

FIGURE 27

The effect of feed rate to a basket centrifuge on the resulting cake

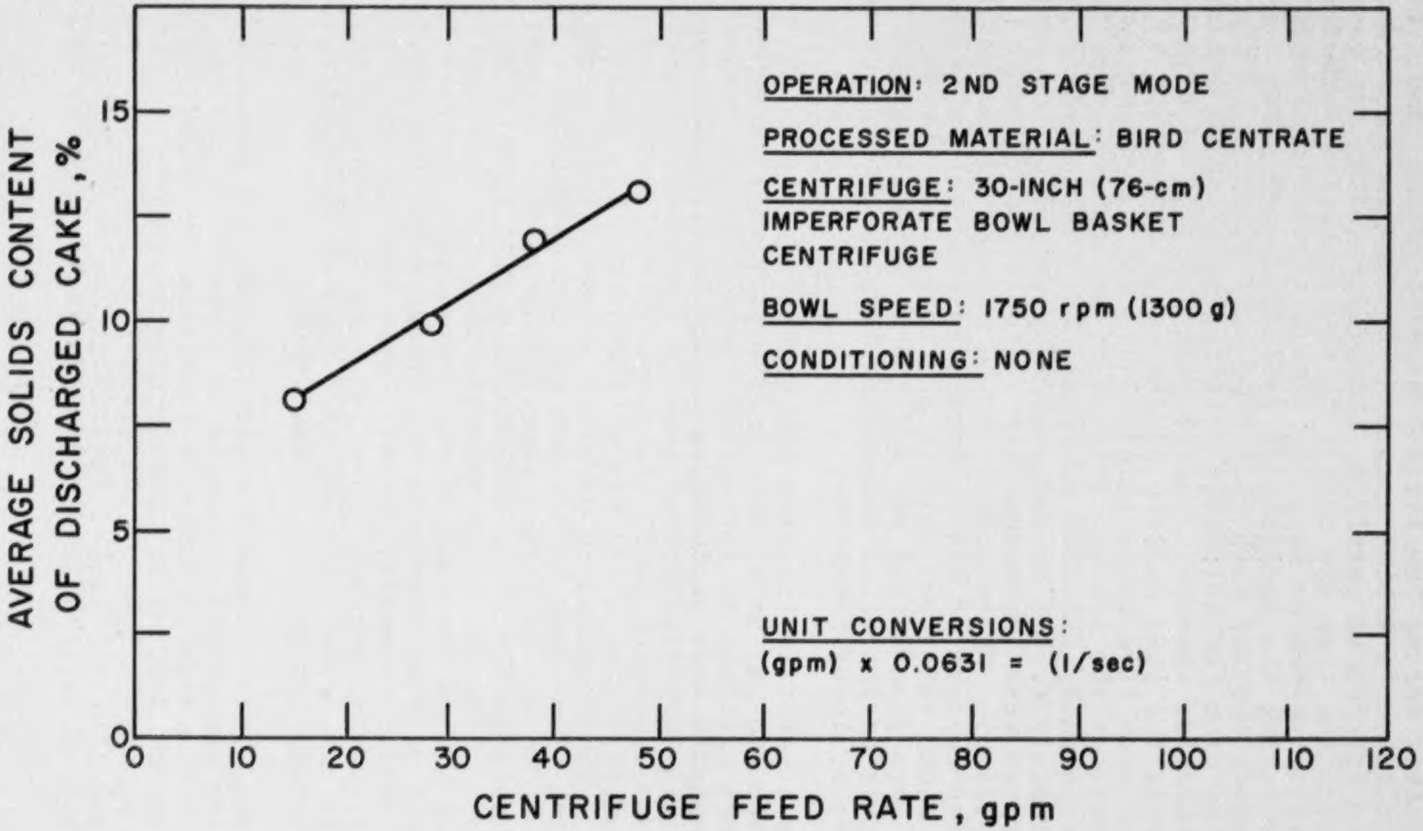


Table 25: DATA* SUMMARIZING THE EFFECT OF POLYMER ADDITION ON THE DEWATERING PERFORMANCE OF A BASKET CENTRIFUGE AT VARIOUS FEEDRATES.

PARAMETERS

1. Operation:........ 2nd stage mode
2. Feed Material:.... 'Bird' centrate
3. Centrifuge:....... 40-inch (102-cm) Sharples basket centrifuge
4. Bowl Speed:....... 1500 rpm (1300 G's)
5. Polymer:.......... Dow C-41
6. Polymer Dosage:... 4 lbs/ton(2.0 kg/metric ton)

FEEDRATE	FEED TIME	SUSPENDED SOLIDS CONCENTRATION			SUSPENDED SOLIDS CAPTURE
		'Bird' Centrate Feed	Basket Centrate	Cake	
-gpm-	-min-	-%-	-%-	-%-	-%-
20	5.0	3.13	0.13	22.1	96.4
	14.0		0.14		96.1
	24.0		0.15		95.9
	26.0		0.32		91.0
	27.0		1.02		70.1
30	3.5	3.36	0.14	19.6	96.5
	12.5		0.15		96.3
	15.5		0.34		91.5
	16.5		1.00		74.0
40	3.0	2.79	0.14	19.0	95.7
	5.0		0.14		95.7
	9.0		0.14		95.7
	11.0		0.14		95.7
	13.0		0.86		72.5
	14.0		1.40		53.8
50	3.5	2.97	0.15	18.2	95.4
	6.5		0.15		95.4
	8.5		0.15		95.4
	10.5		0.18		94.9
	11.0		0.41		88.2
	11.5		0.89		73.6
60	3.5	2.42	0.17	16.3	94.0
	4.5		0.17		94.0
	6.5		0.17		94.0
	8.0		0.19		93.2
	9.0		0.34		87.8
	9.5		1.01		62.1

* All data pertain to the tests conducted on 'Bird' centrate , i.e. the centrate effluent discharged from the existing horizontal scroll centrifuge station operating in its normal mode at JWPCP.

Unit Conversions: (gpm) x 0.0631 = (l/sec)
(% Solids) x 10,000 = (mg/l)

base performance evaluation (refer to Table 24), the total time of the feed cycle decreased as the feedrate was increased, respectively. Figure 28 graphically depicts the instantaneous solids capture experienced as a function of feed time for each of the feedrates investigated. The resulting break-through curves display the fact that in the 20-60 gpm (1.26-3.78 l/sec) feedrate range, suspended solid recovery maximums of 94-96 percent, respectively, are obtainable up to some point in time (depending on the feedrate.) At break-through, suspended solids capture rapidly drops off, thereby indicating that tha capacity of the quiescent zone for accumulating solids has been exhausted. As noted, the time of this occurrence decreased with increasing feedrate to the centrifuge and had the corresponding effect of reducing the average solids content in the resulting discharged cakes. This latter effect is graphically depicted in the plot of average cake dryness with feedrate in Figure 29.

Data are presented in Table 26 which summarize the effect of adding various dosages of polymer to a 30-gpm (1.89 l/sec) Bird centrate feedstream in the 40-inch (102-cm) basket centrifuge. For each polymer dosage, instantaneous suspended solid recoveries are plotted as a function of feed cycle time (Figure 30). In addition to promoting a very slight increase in maximum solids capture, increased polymer dosing had the effect of prolonging the duration of a feed cycle before break-through and recovery dropoff occurred. As noted in Table 26, the extended run time enabled more compaction of the accumulated solids to occur in the quiescent zone, thereby providing for an increase in the average solids content of the discharged cakes. The effect is graphically portrayed in the plot in Figure 31.

In conjunction with the effect of feed time and polymer addition, some data were acquired showing the build-up of accumulated solids within the bowl of the basket centrifuge at each of several feedrates. A summary of these data are presented in Table 27 for the situation when the polymer dosage was held constant at 4 lbs/ton (2.0 kg/metric ton). A graphical profile of these data is shown in Figure 32. Displayed is the fact that as captured solids accumulated from the bowl wall to the centrate overflow weir, the localized cake solids content correspondingly decreased. Also, localized cake dryness decreased as the feedrate to the machine was increased. Regarding the profile, it is to be noted that the first

FIGURE 28

Solids recovery in a basket centrifuge at different time intervals during feed cycles at various feed rates

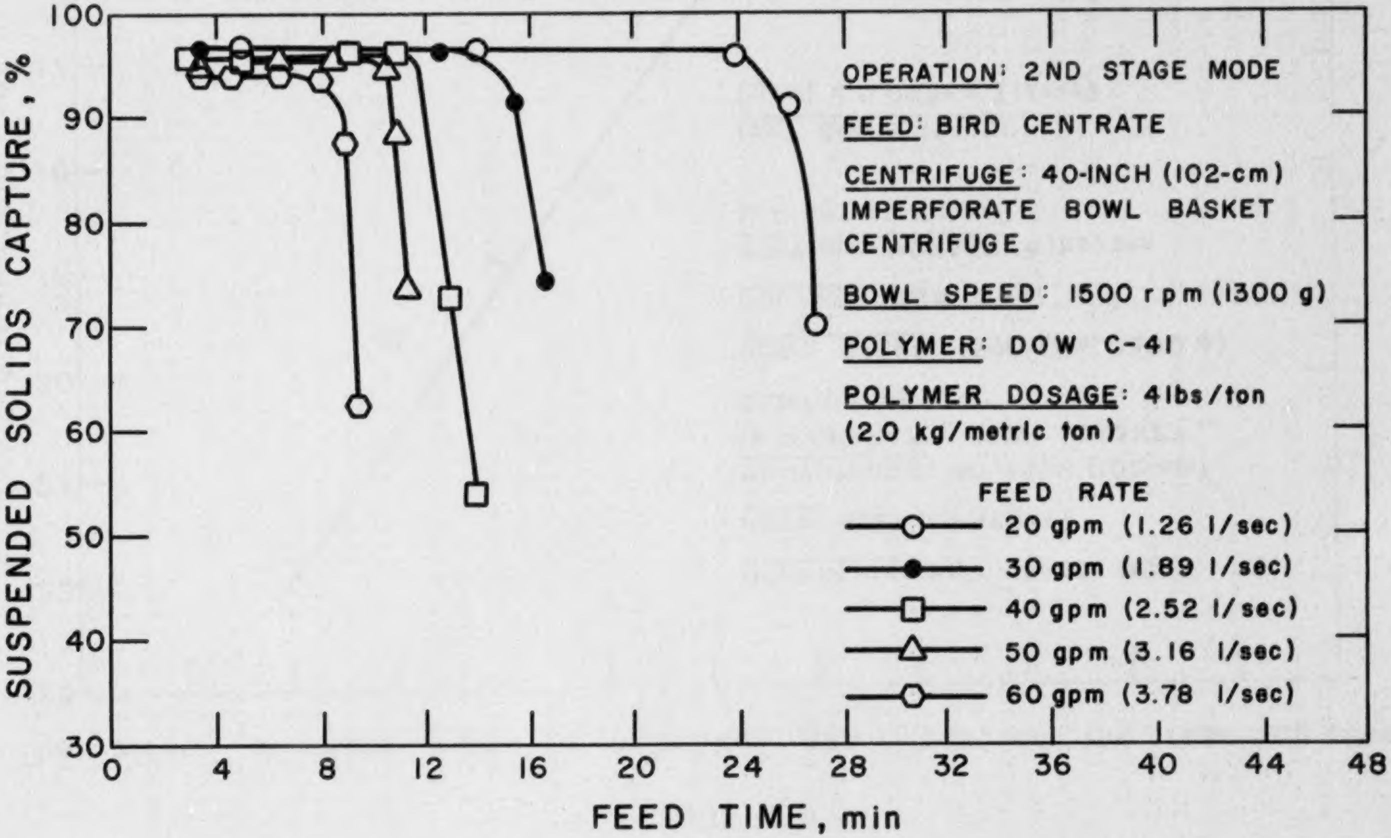


FIGURE 29

The effect of feed rate to a basket centrifuge on the resulting cake

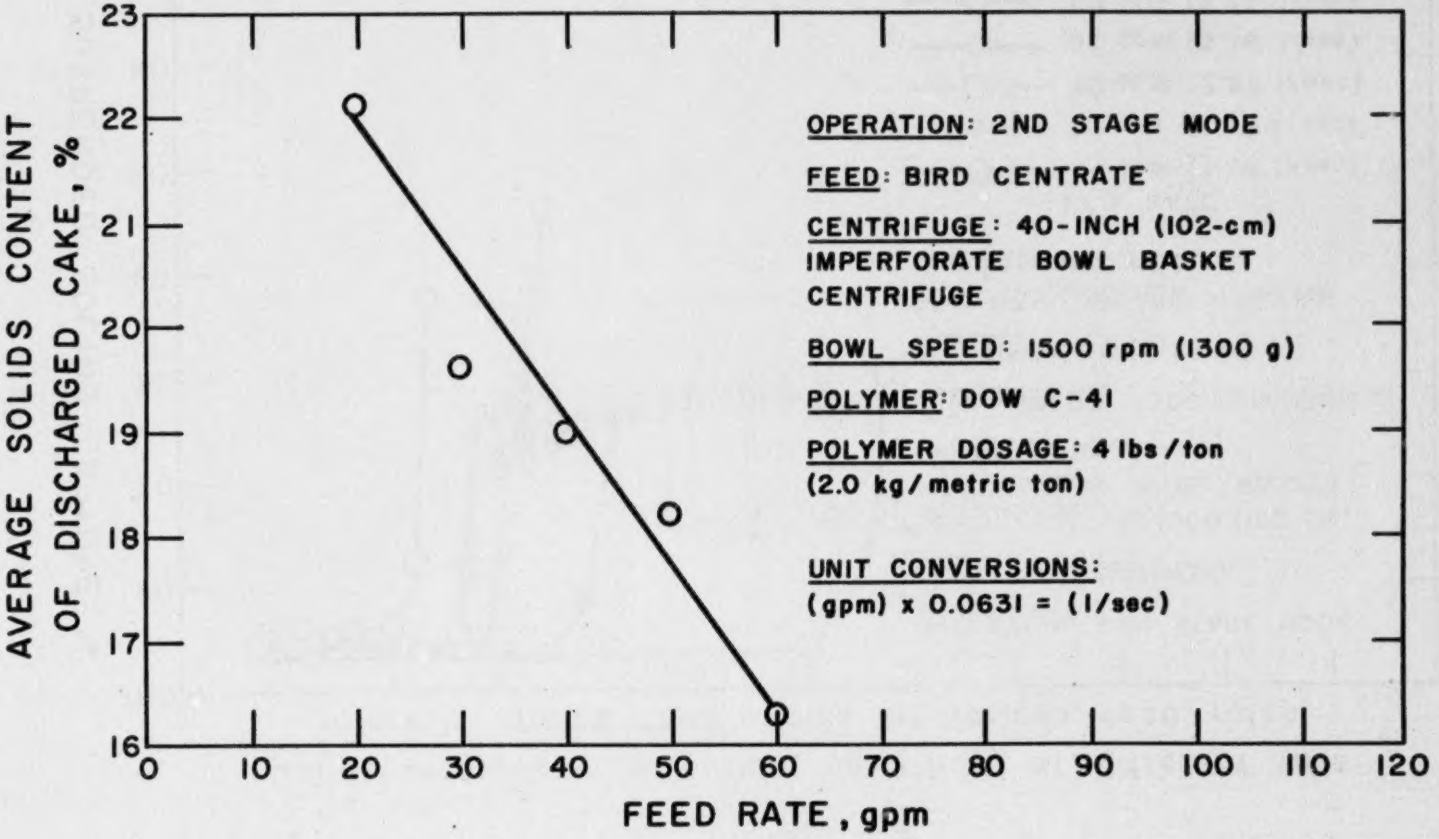


Table 26: DATA* SUMMARIZING THE EFFECT OF VARYING POLYMER DOSAGES ON THE DEWATERING PERFORMANCE OF A BASKET CENTRIFUGE.

PARAMETERS

1. Operation:....... 2nd stage mode
2. Feed Material:... 'Bird' centrate
3. Feed Rate:....... 30 gpm (1.89 l/sec)
4. Centrifuge:...... 40-inch (102-cm) Sharples Basket Centrifuge
5. Bowl Speed:...... 1500 rpm (1300 G's)
6. Polymer:......... Dow C-41

FEED TIME	SUSPENDED SOLIDS CONCENTRATION			POLYMER DOSAGE	SUSPENDED SOLIDS CAPTURE
-min-	'Bird' Centrate Feed -%-	Basket Centrate -%-	Cake -%-	-%-	-%-
3.5	2.79	0.14	16.4	~2	95.8
6.5		0.14			95.8
9.5		0.16			95.2
10.5		1.25			59.8
3.5	3.36	0.14	19.6	~4	96.5
12.5		0.15			96.3
15.5		0.34			91.5
16.5		1.00			74.0
3.5	2.84	0.10	22.1	~9	96.9
12.5		0.10			96.9
17.5		0.11			96.6
19.5		0.63			80.1
20.5		1.87			37.3

*All data pertain to the tests conducted on 'Bird' centrate , i.e. the centrate effluent discharged from the existing horizontal scroll centrifuge station operating in its normal mode at JWPCP.

Unit Conversions: (% Solids) x 10,000 = (mg/l)
(lbs/ton) x 0.5 = (kg/metric ton)

FIGURE 30

The influence of polymer dosage on suspended solids recovery in a basket centrifuge

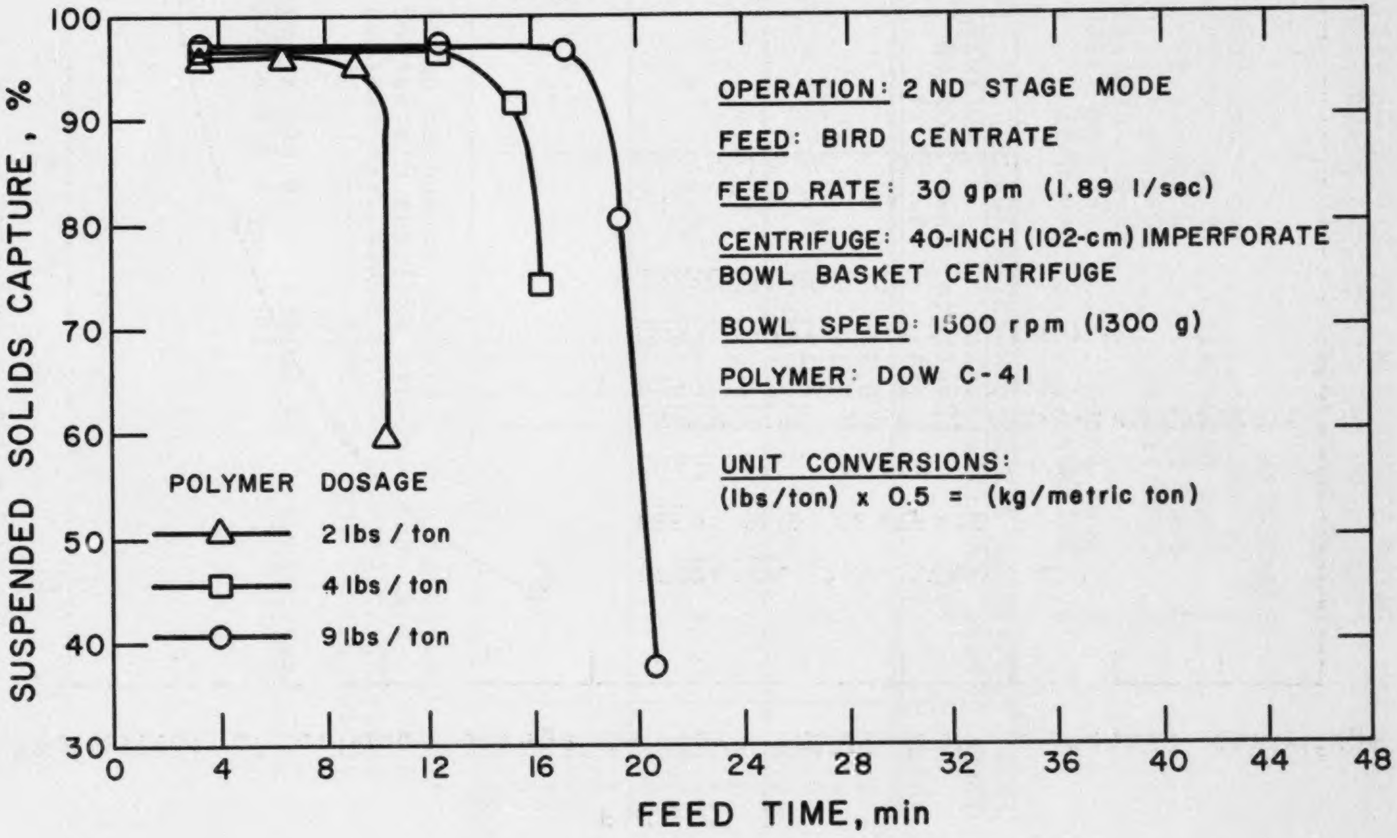


FIGURE 31

The effect of polymer dosage on cake solids from a basket centrifuge

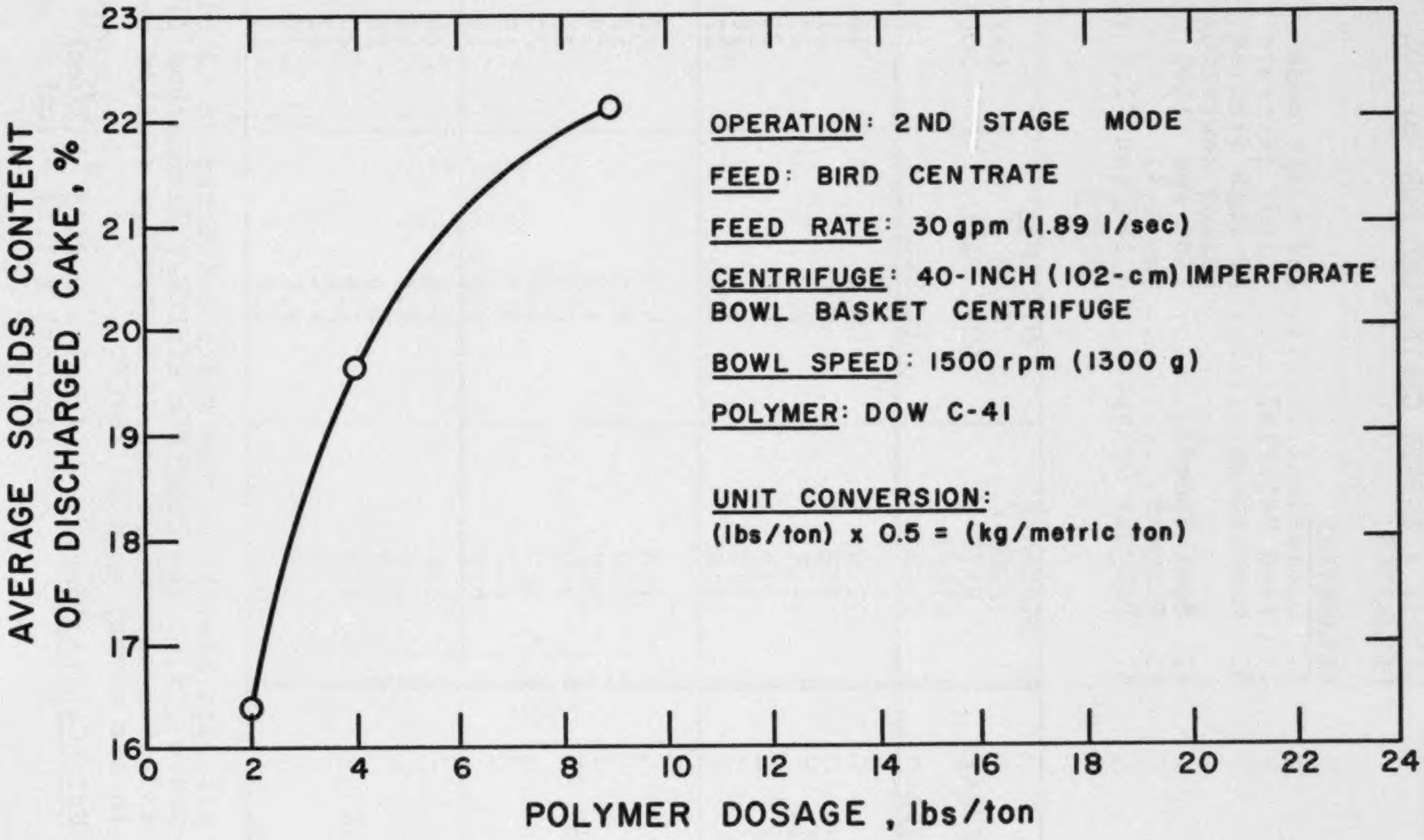


Table 27: DATA* SUMMARIZING THE BUILD-UP OF CAKE SOLIDS WITHIN A BASKET CENTRIFUGE FOR VARIOUS FEEDRATES.

PARAMETERS

1. Operation:........ 2nd stage mode
2. Feed Material:.... 'Bird' centrate
3. Centrifuge:....... 40-inch (102-cm) Sharples basket centrifuge
4. Bowl Speed:....... 1500 rpm (1300 G's)
5. Polymer:.......... Dow C-41
6. Polymer Dosage:... 4 lbs/ton (2.0 kg/metric ton)

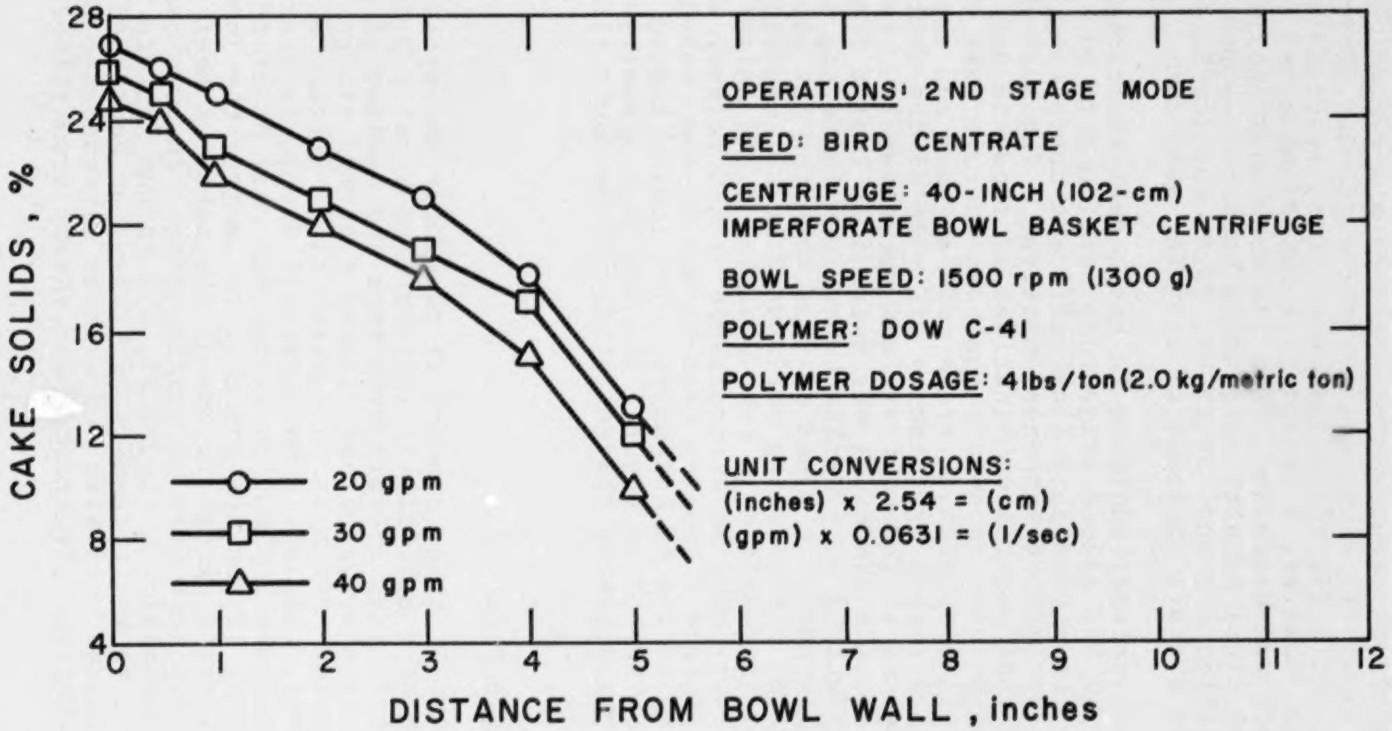
FEEDRATE -gpm-	DISTANCE FROM WEIR CREST -inches-	DISTANCE FROM BOWL WALL -inches-	CAKE SOLIDS -%-
20	1.0	5.0	13
	2.0	4.0	18
	3.0	3.0	21
	4.0	2.0	23
	5.0	1.0	25
	5.5	0.5	26
	6.0	0.0	27
30	1.0	5.0	12
	2.0	4.0	17
	3.0	3.0	19
	4.0	2.0	21
	5.0	1.0	23
	5.5	0.5	25
	6.0	0.0	26
40	1.0	5.0	10
	2.0	4.0	15
	3.0	3.0	18
	4.0	2.0	20
	5.0	1.0	22
	5.5	0.5	24
	6.0	0.0	25

* All data pertain to the tests conudcted on 'Bird centrate , i.e. the centrate effluent discharged from the existing horizontal scroll centrifuge station operating in its normal mode at JWPCP.

Unit Conversions: (gpm) x 0.0631 = (l/sec)
(inches) x 2.54 = (cm)

FIGURE 32

Profile of cake solids buildup in a basket centrifuge at various feed rates



OPERATIONS: 2 ND STAGE MODE

FEED: BIRD CENTRATE

CENTRIFUGE: 40-INCH (102-cm) IMPERFORATE BOWL BASKET CENTRIFUGE

BOWL SPEED: 1500 rpm (1300 g)

POLYMER: DOW C-41

POLYMER DOSAGE: 4 lbs/ton (2.0 kg/metric ton)

UNIT CONVERSIONS:
(inches) x 2.54 = (cm)
(gpm) x 0.0631 = (l/sec)

one-inch (2.5-cm) of accumulated material was skimmed off and discarded. Thus, the material in the remaining 5-inch (12.7-cm) annular ring would have average solids contents of 21.7%, 20.1% and 18.9% for the 20, 30 and 40 gpm (1.26, 1.89, and 2.52 l/sec) runs, respectively. If instead, however, 2 inches (5.1 cm) of material were skimmed off and discarded, then the remainder in the 4-inch (10.2-cm) annular ring would have corresponding average solids contents of 23.0%, 21.4% and 20.2%, respectively--an overall increase of 1.3% for each run.

In summary, polymer addition to the basket centrifuge operating in the second stage mode was found to be necessary for producing a final effluent containing 1500 mg/l or less of suspended material. The test data indicated that several combinations of feedrate and polymer dosage can be used to obtain the same average cake dryness. In an actual operation, average cake dryness can also be increased simply by skimming off more of the wetter material close to the weir lip and recycling it. For the operation at the JWPCP, it was determined that a 20% cake would be required of a basket centrifuge operating in the second stage mode. A blend of this with the 35% cakes produced from the existing horizontal scroll centrifuge station would result in a cake mixture of 25% solids by weight. This could be accomplished with a polymer dosage of approximately 4 lbs/ton (2.0 kg/metric ton) based on feed solids to the basket units. This corresponded to a dosage requirement of about 3 lbs/ton (1.5 kg/metric ton) based on the digested sludge solids fed to the system as a whole.

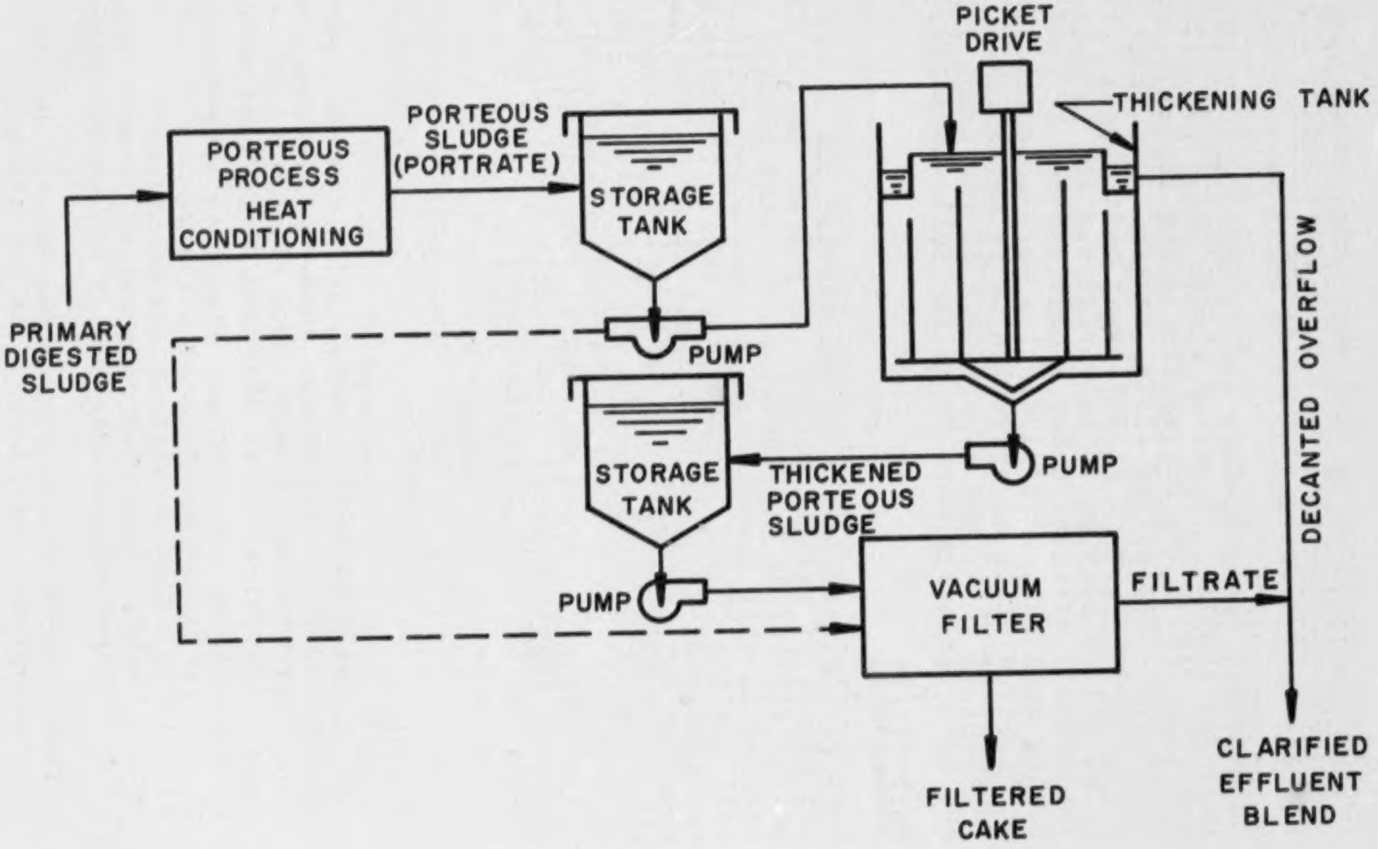
VACUUM FILTRATION

The vacuum filtration studies at the JWPCP encompassed an evaluation of a coil filter (rotary drum type) and two cloth belt filters (rotary drum type and horizontal belt type) for dewatering either primary digested sludge or Bird centrate. Attempts to dewater Bird centrate were, in all cases, completely unsuccessful due to lack of significant cake buildup on either the coil or cloth belts. Also, it was not possible to dewater the JWPCP primary digested sludge in any of the units without incorporating some form of conditioning. In accordance with the schematic in Figure 33, all vacuum filters were assessed as to their capability to dewater heat-conditioned digested sludge both with and without intermediate portrate thickening. Regarding both rotary drum filters,

FIGURE 33

Schematic flow diagram

Dewatering of thickened and unthickened portrate by vacuum filtration



two other conditioning aids were considered, namely chemical conditioning with ferric chloride and/or lime, and polymer conditioning with Nalco 610.

In general, the procedure for evaluating each filter unit was similar. Digested sludge was first conditioned and then fed to the respective vacuum filter being tested. Under each conditioned state, several filtration runs were conducted, each at different belt speeds. This enabled solids loading to be varied and its influence to be independently assessed under a constant set of conditions. During each run, several minutes were allocated for an equilibrium state of operation to be established. Pursuant to this, one sample each of the feed, filtrate and cake discharge were taken for followup solids analysis.

Coil Filter

Some preliminary test work was carried out to assess the effect of various dosages of polymer (Nalco 610) on the filtration properties of digested sludge. Considered in this respect were polymer doses ranging from 0-25 lbs/ton (0.0-12.5 kg/metric ton). The test work was conducted with the belt speed fixed to provide a constant solids loading of approximately 5 lbs/hr/sq ft (24.4 kg/hr/sq m)--a loading considerably low for this type of operation but purposely selected to insure adequate cake formation. Based on several runs carried out at each of several polymer doses within the investigated range, the following was concluded:

(1) At polymer dosages between 0-4 lbs/ton (0.0-2.0 kg/metric ton), solids recovery was negligible.

(2) At a polymer dosage of 5 lbs/ton (2.5 kg/metric ton), solids recovery was sparsely achieved; when experienced, generated cakes were about 23% solids by weight but were thin and discharged poorly.

(3) Solids recovery was regularly experienced at a polymer dose of 6 lbs/ton (3.0 kg/metric ton) but erratically ranged from 62-95 percent capture; filter cakes ranged from 19-21% solids by weight.

(4) Solids recovery remained erratic in the polymer dosage range of 7-9 lbs/ton (3.5-4.5 kg/metric ton) but decreasingly

so as the upper dosage was approached; generated cakes ranged between 16-20% solids by weight at each dosage interval.

(5) At a polymer dosage of 10 lbs/ton (5.0 kg/metric ton), solids recovery stabilized between 90-98 percent capture; polymer dosages beyond this did nothing to enhance this situation. Cake quality remained within a constant range of 16-20% solids by weight.

Based on the above, it was decided that a polymer dosage of at least 10 lbs/ton (5.0 kg/metric ton) would be required to consistently produce a filtrate having an average suspended solids concentration of 1500 mg/l. It was also decided that the filter loading study would be carried out under this fixed condition.

Presented in Table 28 are data summarizing the effect of loading rate on the coil filter's capability of dewatering the JWPCP digested sludge conditioned with 10 lbs/ton (5.0 kg/metric ton) of Nalco 610. As noted, the table is comprised of data acquired from four individual runs, each from a different day. The effect of loading rate on suspended solids capture for each of these runs is graphically depicted in Figure 34. A comparison of the curves reveals that throughout the investigated range of loading rates, the capture of suspended solids varied between 87-99 percent. Regarding two of the runs, solid recoveries of 97 percent or better were consistently obtained. The observed differences might be attributed to day-to-day variations in the particle size distribution within the sludge material itself. This would likely have an effect on the body of the formed cake doing the filtering. Because of the large porosity factor in coil filters, slight changes in cake body would significantly affect filtration performance. Similar observations were encountered in other runs not reported on herein. Overall, though, an average suspended solids recovery of 95% was achieved. For the most part, discharged cakes were at 18% (±2%) solids by weight. As in the horizontal scroll centrifuge tests, this demonstrated the contribution of bound water associated with the capture of finely suspended particles from the sludge feed material.

Regarding chemical conditioning, coil filtration tests were conducted in conjunction with ferric chloride and lime dosages ranging, respectively, from 40-120 lbs/ton

Table 28: DATA* SUMMARIZING THE EFFECT OF LOADING RATE ON THE FILTRATION CHARACTERISTICS OF POLYMER CONDITIONED DIGESTED SLUDGE IN A VACUUM COIL FILTER.

PARAMETERS
1. Filter:........... Komline Sanderson coil filter
2. Vacuum:........... form & dry pressure differential @ 12-inches Hg (305-mm Hg)
3. Polymer:.......... Nalco 610
4. Polymer Dosage:... ~10 lbs/ton (5.0 kg/metric ton)

SUSPENDED SOLIDS CONCENTRATION				CALCULATED SOLIDS LOADING -lbs/hr/sq ft-	SUSPENDED SOLIDS CAPTURE*** -%-
Uncon-ditioned -%-	Con-ditioned** -%-	Filtrate -%-	Filter Cake -%-		
4.05	3.47	0.44	18.2	11.1	89.5
4.06	3.48	0.19	17.8	13.7	95.6
4.08	3.50	0.53	18.0	16.3	87.4
3.52	3.02	0.46	18.0	6.9	87.0
3.48	2.98	0.26	17.2	9.4	92.7
3.50	3.00	0.08	18.1	12.0	97.8
3.47	2.98	0.08	21.7	5.2	97.7
3.69	3.16	0.07	18.4	6.9	98.2
3.88	3.33	0.07	18.0	10.3	98.3
3.89	3.34	0.04	18.8	12.9	99.0
3.90	3.34	0.07	19.8	15.4	98.3
4.43	3.80	0.10	17.0	8.6	97.9
4.27	3.66	0.14	18.0	12.0	96.9
4.51	3.87	0.10	17.8	14.6	98.0
4.47	3.83	0.14	17.2	18.0	97.1

*All data pertain to filtration studies on JWPCP primary digested sludge.

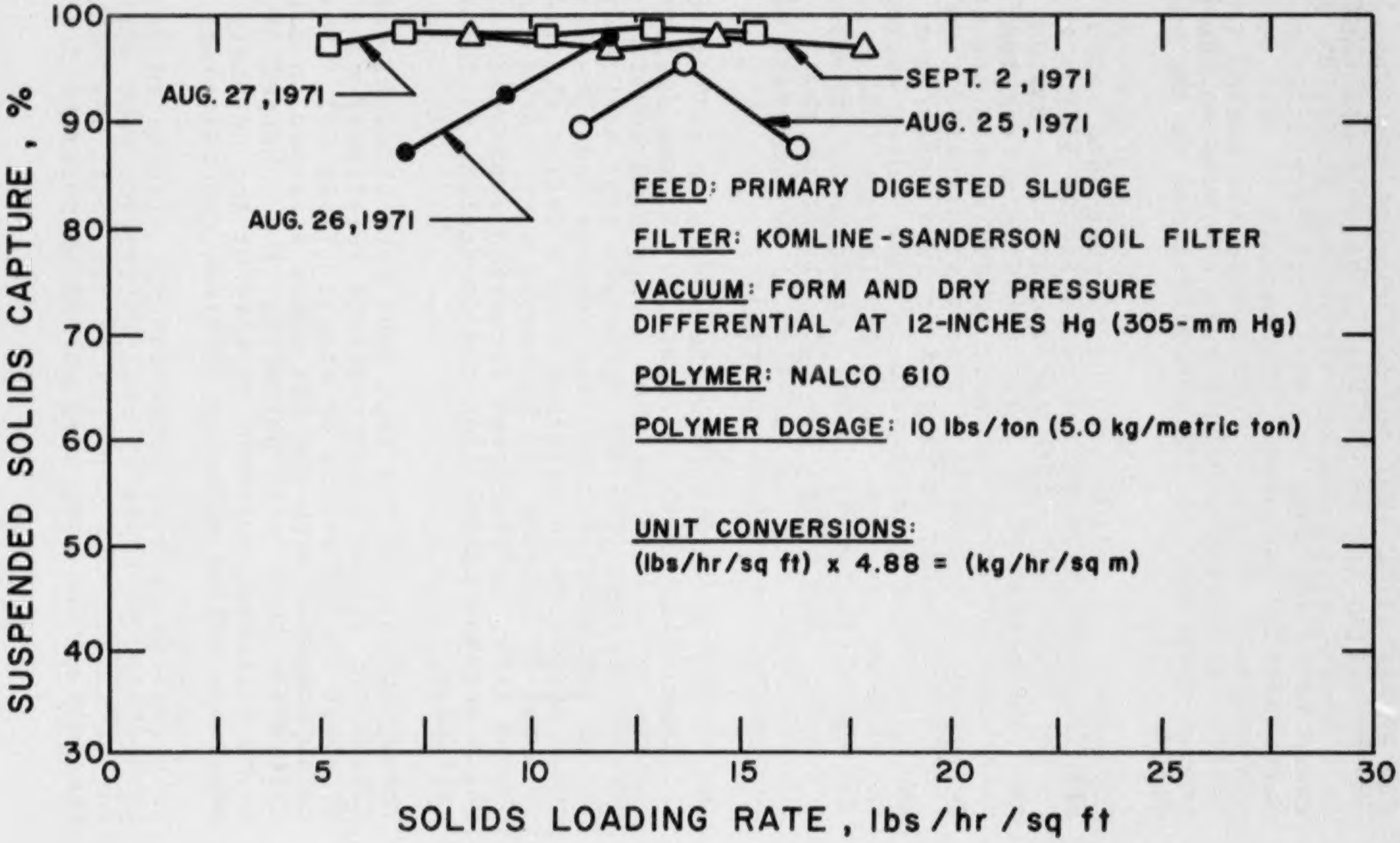
**Data corrected for the addition of polymer solution batched at a concentration of 1250 mg/1.

***Computed values are based on suspended solids in the conditioned feed.

Unit Conversions: (lbs/hr/sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/1)

FIGURE 34

Solids recovery from polymer conditioned digested sludge in a coil filter at various loading rates



(20-60 kg/metric ton) and 500-600 lbs/ton (250-300 kg/metric ton) as $Ca(OH)_2$. The work was conducted in a manner which enabled variations in solids loading rates to be included and their relative influence to be independently assessed. The results of this work are summarized in Table 29. As noted, the listed solids loading and capture values were computed on the basis of actual suspended solids concentrations in the conditioned feed.

The effect of solids loading on suspended solids recovery is graphically portrayed in Figure 35 for two lime dosage situations, both incorporating a constant ferric chloride dosage of 80 lbs/ton (40 kg/metric ton). In both cases, a rapid decrease in solids capture was experienced as the loading rate was increased from 1.6 to 3.2 lbs/hr/sq ft (7.8 to 15.6 kg/hr/sq m). For any particular loading rate in this range, increasing the lime dosage from 500 to 600 lbs/ton (250-300 kg/metric ton) as $Ca(OH)_2$ effected an increase in recovery. The effect was only slight at the 1.6 lbs/hr/sq ft (7.8 kg/hr/sq m) loading rate whereat maximum solids capture occurred.

The effect of ferric chloride dosage on solids recovery is graphically shown in Figure 36 for two different loading rates with the lime dosage held constant at 550-600 lbs/ton (275-300 kg/metric ton) as $Ca(OH)_2$. Though somewhat sketchy, the results indicate that optimum operation is attained with a ferric chloride dosage of about 80 lbs/ton (40 kg/metric ton). At dosages beyond this, an overdosed situation apparently occurred which negated coagulation and dewatering of the sludge particles.

Throughout all of the test runs with chemical conditioning, discharged filter cakes remained relatively constant at about 25-26% solids by weight (Table 29). This is to be compared with the 18% cakes attained in coil filtration tests with polymers. The enhanced dryness is to be expected, however, in view of the quantity of insoluble solids added by chemical conditioning.

With regards to heat conditioning, efforts to dewater unthickened portrate by coil filtration were entirely unsuccessful. The porosity of the coils was such that the bulk of the suspended solids in portrate fed to the

Table 29: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF CHEMICALLY CONDITIONED DIGESTED SLUDGE IN A VACUUM COIL FILTER

PARAMETERS

1. Filter:... Komline Sanderson coil filter
2. Vacuum:... form & dry pressure differential @ 12-inches Hg (305-mm Hg)

CHEMICAL DOSAGE		SUSPENDED SOLIDS CONCENTRATION				CALCULATED SOLIDS LOADING	SUSPENDED SOLIDS CAPTURE***
		Sludge Feed		Filtrate	Filter Cake		
Fe Cl_3 -lbs/ton-	Lime as $Ca(OH)_2$ -lbs/ton-	Uncon-ditioned -%-	Con-ditioned** -%-	-%-	-%-	-lbs/hr/ sq ft	-%-
40	560	3.73	3.04	0.51	25.9	1.6	84.9
				1.57	26.1	2.4	51.5
80	500	3.54	2.88	0.36	24.2	1.6	88.8
				0.70	25.7	2.4	77.8
				1.58	26.0	3.3	48.1
	600	3.54	2.85	0.25	25.8	1.6	92.1
				0.47	26.0	2.4	85.0
				1.18	26.1	3.2	61.4
120	600	3.42	2.71	1.70	26.0	1.6	39.9

*All data pertain to filtration studies on JWPCP primary digested sludge.

**Data corrected for the addition of lime and Fe Cl_3 solutions batched at 2% and 1% concentrations, respectively.

***Computated values are based on suspended solids in the conditioned feed.

Unit Conversions:

(lbs/ton) x 0.5 = (kg/metric ton)
(lbs/hr/ sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/l)

FIGURE 35

Solids recovery in a coil filter at two different lime dosages for various loading rates

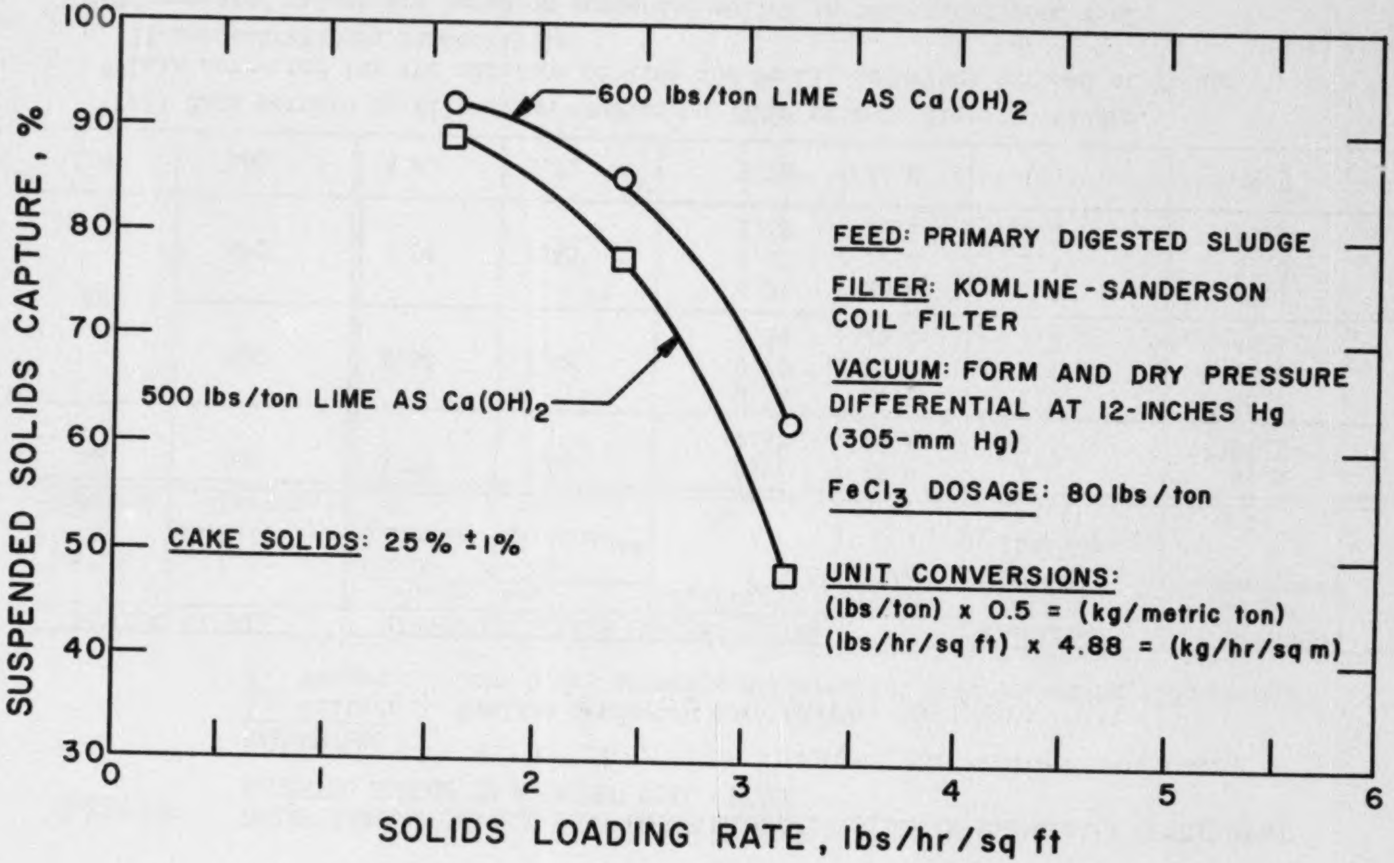
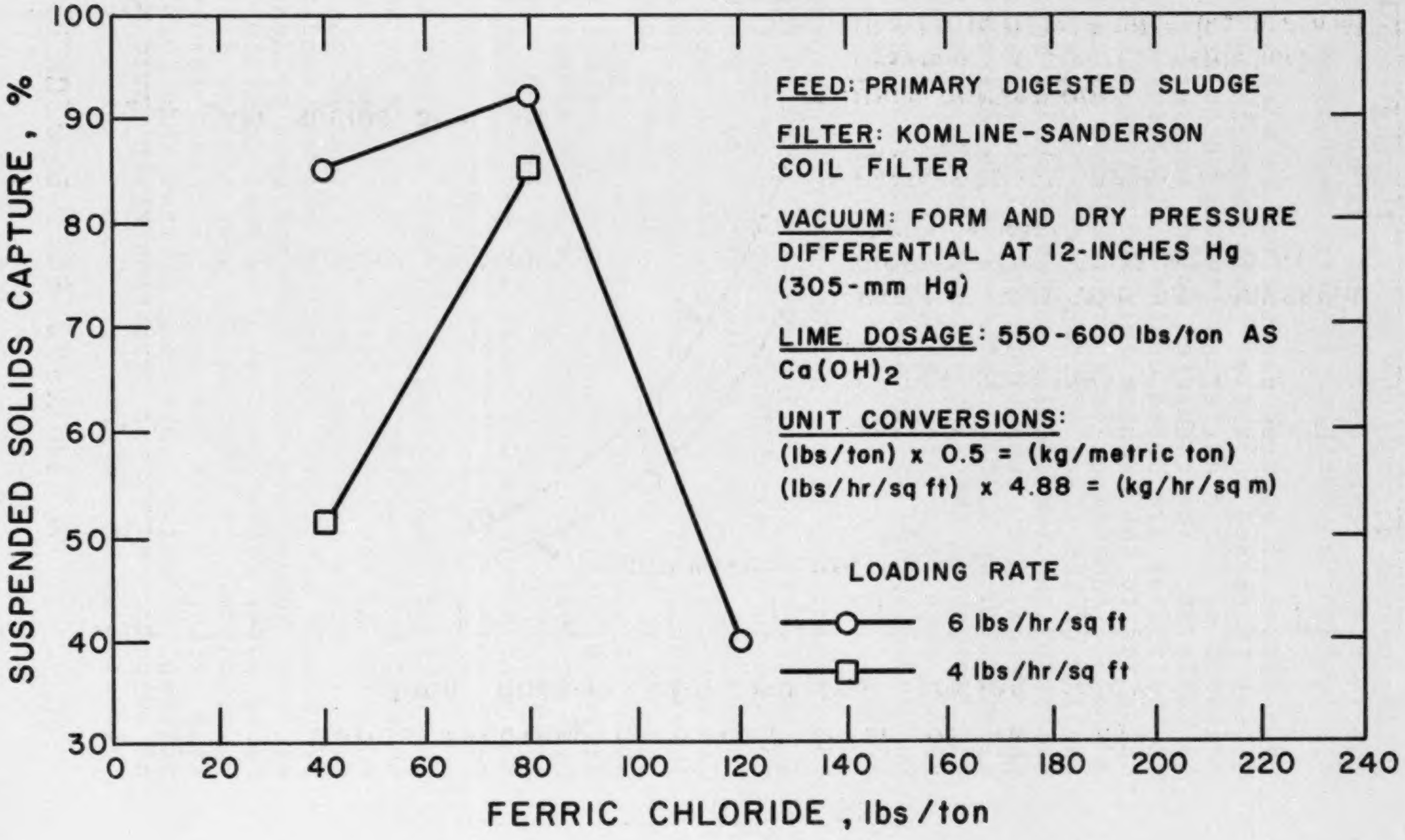


FIGURE 36

The effect of ferric chloride dosage on solids recovery in a coil filter at two different loading rates



filter passed through the coils, thereby remaining in the filtrate. Cake development was nil. Hence the application was declared totally ineffective.

Some degree of success was arrived at with attempts to filter thickened portrate. Data summarizing results obtained at three different loading rates are presented in Table 30. The tabulated solids recovery effected by the filter are based on the initial suspended solids being fed to the machine only and not to the system as a whole. Additional data are tabulated which show the quality of the final effluent blend (decantate plus filtrate) and the overall suspended solids removal by the system, i.e. removal by thermal volatization, elimination by thermal transfer to the dissolved phase, and capture in the filter cake. These latter removal values were calculated on the basis of 3.5% (35,000 mg/1) suspended solids in the waste digested sludge fed to the system.

For comparison, filter solids capture and suspended solids removal by the system are plotted in Figure 37 as a function of solids loading applied to the filter. Increasing the solids loading from 3 to 7 lbs/hr/sq ft (14.6 to 34.2 kg/hr/sq m) resulted in a rapid decrease in captured solids and a corresponding decrease in that removed by the system. Even at the lowest loading only about 70 percent solids removal was attained. The poor filtrate qualities listed in Table 30 reflect the problem of coil porosity coupled with the effect of heat conditioning on particle size distribution. Evidently, the floc particles are small and pass through the filter coils quite readily with the filtrate.

The data of Table 30 indicated that a slight decrease in cake solids content (31% to 28% solids by weight) occurred as the loading rate was increased. In comparison to those cakes generated in either of the two previously discussed chemical or polymer conditioning systems, these were much drier and gave evidence of the bound water release effected by heat conditioning. Unfortunately, a blend of the poor quality filtrates with decantate from the picket thickener resulted in effluent mixtures containing greater than 10,000 mg/1 of suspended solids--a situation which would not be tolerated at the JWPCP.

Table 30: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF THICKENED HEAT-CONDITIONED DIGESTED SLUDGE BY VACUUM COIL FILTRATION

PARAMETERS

1. Processed Material:........ JWPCP primary digested sludge
2. Porteous Conditioning:..... 40 min @ 350°F (175°C)
3. Thickener Overflow Rate:... 225 gpd/sq ft (9.2 cu m/day/ sq m)
4. Filter:.................... Komline-Sanderson coil filter
5. Vacuum:.................... form & dry pressure differential @ 12-inches Hg (305-mm Hg)

SUSPENDED SOLIDS CONCENTRATION			CALCULATED FILTER SOLIDS LOADING	SUSPENDED SOLIDS CAPTURE IN FILTER	SUSPENDED SOLIDS IN EFFLUENT BLEND (Filtrate + Decantate)	TOTAL SUSPENDED SOLIDS REMOVAL BY SYSTEM**
Thickened Portrate Feed -%-	Filtrate -%-	Filter Cake -%-	-lbs/hr/sq ft-	-%-	-%-	-%-
5.93	2.30	31.2	3	66.1	1.08	71.6
5.64	3.14	29.0	5	49.7	1.48	60.8
5.00	4.54	28.1	7	11.0	2.37	35.3

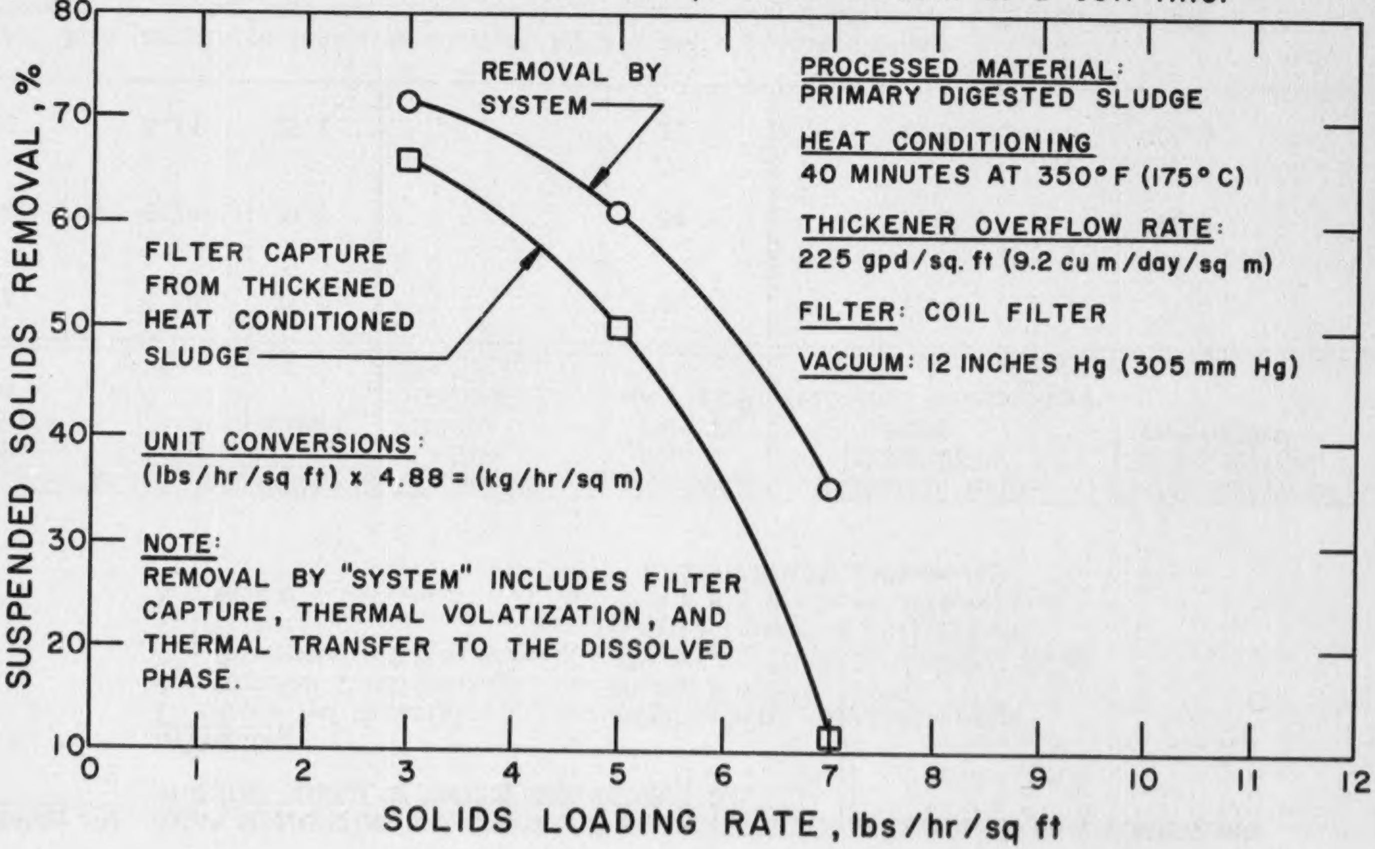
*All data pertain to test conducted on JWPCP primary digested sludge.

**Removal by "System" includes filter capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values are based on a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions: (lbs/hr/sq ft) x 4.88 = (kg/hr sq m)
(% Solids) x 10,000 = (mg/l)

FIGURE 37

Suspended solids removal from digested sludge fed to a system incorporating heat conditioning, intermediate thickening and vacuum filtration of the thickened portrate stream in a coil filter



In review, coil filtration tests incorporating polymer conditioning at 10 lbs/ton (5.0 kg/metric ton) yielded the highest solids loading rate -- approximately 18 lbs/hr/sq ft (87.8 kg/hr/sq m); filter cakes, however, were wettest (18% solids by weight). Solid captures of 92 percent and cake qualities of 25-26% solids by weight were experienced with lime and ferric chloride dosages of 600 lbs/ton (300 kg/metric ton) as $Ca(OH)_2$ and 80 lbs/ton (40 kg/metric ton), respectively; these results could only be accomplished, however, at a loading rate of about 1.5 lb/hr/sq ft (7.3 kg/hr/sq m) -- a rate deemed economically impractical for a coil filter operation. Finally, driest cakes (approximately 30% solids by weight) were attained in the thermal-thickening-filtration system; solids removal (maximum of 70 percent) was poorest not to mention the impractical low loading rate of 3 lbs/hr/sq ft (14.6 kg/hr/sq m) necessary to achieve this.

Rotary-Belt Vacuum Filter

Specific resistance (SR) determinations and filter leaf tests were conducted in the laboratory prior to actual belt filtration tests. The derived information proved useful in eliminating much of the pilot plant work that would have otherwise been necessary. For example, SR tests revealed that under a differential vacuum pressure of 20-25 inches Hg (505-630 mm Hg), cloth belt filtration of heat-conditioned digested sludge would not be possible without intermediate thickening. Similar tests also revealed that digested sludge would not filter directly unless preconditioned with at least 10 lbs/ton (5.0 kg/metric ton) of a cationic polymer (Nalco 610) or 400 lbs/ton (200 kg/metric ton) of lime as $Ca(OH)_2$. Filter leaf tests conducted with six different synthetic cloth materials enabled three to be selected for pilot testing. In the actual pilot plant work, best results were achieved with one belt material (Polypropylene 854-F) regardless of the type of conditioning. For purposes of this report, only those results will be presented herein.

Data summarizing the dewatering characteristics of polymer and lime conditioned digested sludge in an Eimco-belt vacuum filter are presented in Tables 31 and 32, respectively. Those of thickened heat-conditioned digested sludge are presented in Table 33. As noted in Table 32, data are presented for lime dosages of 400, 600 and 800 lbs/ton (200,300 and 400 kg/metric ton) as $Ca(OH)_2$ with

Table 31: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF POLYMER CONDITIONED DIGESTED SLUDGE IN A ROTARY-BELT VACUUM FILTER

PARAMETERS
1. Filter:........... Eimcobelt vacuum filter
2. Belt Material:.... Polypropylene 854-F
3. Vacuum:........... form & dry pressure differential @ 25-inches Hg (630-mm Hg)
4. Polymer:.......... Nalco 610
5. Polymer Dosage:... 10 lbs/ton (5 kg/metric ton)

SUSPENDED SOLIDS CONCENTRATION			CALCULATED SOLIDS LOADING -lbs/hr/sq ft-	SUSPENDED SOLIDS CAPTURE -%-	CAKE DISCHARGE PROPERTIES
Conditioned Sludge Feed -%-	Filtrate -%-	Filter Cake -%-			
3.78	0.06	22.3	0.9	98.7	Poor
3.91	0.04	18.2	1.0	99.2	Poor
3.79	0.05	18.9	1.1	98.9	Poor

*All data pertain to filtration studies on JWPCP primary digested sludge.

Unit Conversions: (lbs/hr/sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/l)

Table 32: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF CHEMICALLY CONDITIONED DIGESTED SLUDGE IN A ROTARY-BELT VACUUM FILTER.

PARAMETERS
1. Filter:.......... Eimco belt vacuum filter
2. Belt Material:... Polypropylene 854-F
3. Vacuum:.......... form & dry pressure differential @ 25-inches Hg (630-mm Hg)
4. Fe Cl_3 Dosage:... None

LIME DOSAGE as $Ca(OH)_2$ -lbs/ton-	SUSPENDED SOLIDS CONCENTRATION			CALCULATED SOLIDS LOADING	SUSPENDED SOLIDS CAPTURE	CAKE DISCHARGE PROPERTIES
	Conditioned Sludge Feed -%-	Filtrate -%-	Filter Cake -%-	-lbs/hr/sq ft-	-%-	-%-
400	4.45	0.05	28.4	0.8	99.1	Good
	4.37	0.09	36.6	0.9	98.2	Good
	4.17	0.08	31.6	1.1	98.3	Fair
600	4.60	0.02	32.8	1.3	99.6	Good
	4.63	0.03	35.2	1.5	99.4	Good
	4.55	0.02	36.8	1.7	99.6	Fair
800	5.37	0.01	33.1	1.5	99.8	Good
	5.28	0.01	34.5	1.7	99.8	Good
	5.29	0.02	35.0	2.0	99.7	Fair
	5.33	0.04	34.3	2.2	99.4	Poor

*All data pertain to filtration studies on JWPCP primary digested sludge.

Unit Conversions:
(lbs/ton) x 0.5 = (kg/metric ton)
(lbs/hr/sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/l)

Table 33: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF THICKENED HEAT-CONDITIONED DIGESTED SLUDGE BY ROTARY-BELT VACUUM FILTRATION

PARAMETERS

1. Processed Material:........ JWPCP primary digested sludge
2. Porteous Conditioning:..... 40 min @ 350°F (175°C)
3. Thickener Overflow Rate:... 225 gpd/sq ft (9.2 cu m/day/ sq m)
4. Filter:.................... Eimcobelt vacuum filter
5. Belt Material:............. Polypropylene 854-F
6. Vacuum:.................... form & dry pressure differential @ 25-inches Hg (630-mm Hg)
7. Thickened Portrate Feed:... 9.21% suspended solids

SUSPENDED SOLIDS CONCENTRATION		CALCULATED FILTER SOLIDS LOADING	SUSPENDED SOLIDS CAPTURE IN FILTER	CAKE DISCHARGE PROPERTIES	SUSPENDED SOLIDS IN EFFLUENT BLEND (Filtrate + Decantate)	SUSPENDED SOLIDS REMOVAL BY SYSTEM**
Filtrate -%-	Filter Cake -%-	-lbs/hr/sq ft-	-%-		-%-	-%-
0.09	37.4	2.1	99.3	Good	0.31	91.9
0.14	36.5	2.5	98.9	Good	0.32	91.7
0.11	36.4	2.6	99.1	Good	0.32	91.7
0.13	35.7	3.3	98.9	Good	0.32	91.7
0.16	35.8	3.9	98.7	Fair	0.33	91.4
0.49	34.9	4.6	96.0	Poor	0.39	89.9

*All data pertain to test conducted on JWPCP primary digested sludge.

**Removal by "System" includes filter capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values are based on a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions: (lbs/hr/sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/l)

no accompanying ferric chloride dosage. Test work was conducted at each of these in combination with 60 lbs/ton (30 kg/metric ton) of ferric chloride; data results however, were similar to those of Table 32.

Although filtrates of excellent quality were attained in the filtration tests on polymer conditioned sludge (Table 31), the discharge characteristics of the generated filter cakes were, in all cases, poor. At loading rates above 1.1 lbs/hr/sq ft (5.4 kg/hr/sq m), the filter cakes were very thin and wet and, as a consequence, would not discharge at all. Even at the low loading rates shown, the generated cakes were too wet to permit a clean discharge without assistance from the operator. Typically, these 18-20% cakes demonstrate the bound water effect as a consequence of high solids capture (99 percent).

Filtrates of excellent quality were also attained in filtration tests on lime conditioned sludge (Table 32). As opposed to polymer conditioning, the addition of lime served to enhance the dryness of the generated filter cakes. Consequently, loading rates could be adjusted to promote the build-up of thicker cakes which had good discharge properties. When the lime dosage was 400 lbs/ton (200 kg/metric ton) as $Ca(OH)_2$, it was necessary to reduce the loading to 0.9 lbs/hr/sq ft (4.4 kg/hr/sq m) to achieve this result. By increasing this dosage to 600 lbs/ton (300 kg/metric ton) as $Ca(OH)_2$, loadings up to 1.5 lbs/hr/sq ft (7.3 kg/hr/sq m) were possible while still retaining the good cake discharge property; also, filtrate quality was slightly improved and filter cakes were a little drier. Increasing the lime dosage up to 800 lbs/ton (400 kg/metric ton) as $Ca(OH)_2$ did little to improve upon this situation.

In terms of solids loading, vacuum filtration of thickened portrate was best. As shown in Table 33, good cake discharge was possible up to a solids loading of 3.3 lbs/hr/sq ft (16.1 kg/hr/sq m). Cake solids were at 35.7% by weight and the resulting filtrate contained 1300 mg/l of suspended solids. The dry filter cakes lend support to the release of bound water effected by heat conditioning. Based on the suspended solids in the thickened portrate feed, suspended solid captures of about 99 percent were possible with the filter unit. System removals are somewhat lower, however, when consideration is given to the quality of the decantate from the thickener. As noted, overall suspended solids removals of about

92 percent would be experienced by the thermal-thickening-filtration system. The resulting effluent (filtrate plus decantate) would contain about 3200 mg/l of suspended material. On the premise that this effluent would receive some form of biological treatment (required because of the high soluble BOD characteristic induced by thermal conditioning), it was expected that this suspended solid component could be reduced to the 1500 mg/l deemed acceptable for mixing with the JWPCP primary effluent prior to discharge.

Horizontal Belt Filter (Extractor)

As previously mentioned, the extractor pilot plant was only assessed as to its capabilities for dewatering thickened heat-conditioned digested sludge. The cloth belt furnished with the unit was one which was recommended by Eimco representatives as being likely to do a satisfactory job. This recommendation was based on filter leaf tests conducted on the JWPCP's digested sludge after thermal conditioning and thickening.

On the whole, efforts to dewater thickened portrate by vacuum extraction were not too successful. Attempts to load the extractor at a normally typical 20 to 40 lbs/hr/sq ft (97.6 to 195.2 kg/hr/sq m) solids loading resulted in no cake formation whatsoever. In fact, cake formation was not possible until the loading was reduced below 10 lbs/hr/sq ft (48.8 kg/hr/sq m). Further reduction was even necessary before the cake would even halfway discharge by itself.

For the effort involved, only two of the many attempted runs yielded informative data. The results of these runs are tabulated in Table 34. At a solids loading of 3.6 lbs/hr/sq ft (17.6 kg/hr/sq m), a 92.3 percent solids capture was effected by the filter. Generated cakes were at 29.4% solids by weight and had poor discharge properties. Further loading reduction to 2.7 lbs/hr/sq ft (13.2 kg/hr/sq m) served to increase solids capture only slightly. A drier cake (34.6% solids by weight) ensued, however, and the filtrate was of somewhat better quality (8100 mg/l suspended solids). Cake discharge improved slightly but was not consistent. At the lower loading, a resultant blend of the filtrate with the decantate from the thickener would yield an effluent mixture containing 0.44% (4400 mg/l) suspended solids. Overall suspended solids removal from the system would be about 89 percent.

Table 34: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF THICKENED HEAT-CONDITIONED DIGESTED SLUDGE BY VACUUM EXTRACTION

PARAMETERS

1. Processed Material:........ JWPCP primary digested sludge
2. Porteous Conditioning:..... 40 min @ 350°F (175°C)
3. Thickener Overflow Rate:... 225 gpd/sq ft (9.2 cu m/day/ sq m)
4. Filter:.................... Eimco vacuum extractor
5. Cloth Belt:................ manufacturer's recommendation
6. Vacuum:.................... 20-inches Hg (505-mm Hg)

SUSPENDED SOLIDS CONCENTRATION			CALCULATED FILTER SOLIDS LOADING -lbs/hr/sq ft-	SUSPENDED SOLIDS CAPTURE IN FILTER -%-	CAKE DISCHARGE PROPERTIES	SUSPENDED SOLIDS IN EFFLUENT BLEND (Filtrate + Decantate) -%-	SUSPENDED SOLIDS REMOVAL BY SYSTEM** -%-
Thickened Portrate Feed -%-	Filter -%-	Filter Cake -%-					
9.13	0.81	34.6	2.7	93.3	Fair	0.44	88.6
9.84	1.09	29.4	3.6	92.3	Poor	0.49	87.5

*All data pertain to test conducted on JWPCP primary digested sludge.

**Removal by "System" includes filter capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values are based on a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions: (lbs/hr/sq ft) x 4.88 = (kg/hr/ sq m)
(% Solids) x 10,000 = (mg/l)

Even considering any additional removal with followup biological treatment, such a system would be economically impractical due to the low filter loadings required to achieve these results.

PRESSURE FILTRATION

Two types of filter presses were evaluated in this phase of the work, namely a Beloit-Passavant pressure filter and an Eimco diaphragm press. A majority of the research was conducted with the former. Due to the unsuccessful nature of the latter, only a limited amount of work was carried out. The results of the research are presented in the following.

The Beloit-Passavant pressure filter was assessed of its capabilities for dewatering either primary digested sludge or Bird centrate. It was quickly discovered that dewatering of the latter was not a feasible operation due to the extremely wet cakes generated. This was attributed to both the fine nature and low concentration of the suspended solids in the centrate feed material. Therefore, the remaining research with the pressure filter was carried out directly on digested sludge.

Pressure filtration of primary digested sludge could not be accomplished without some form of conditioning. Therefore, the performance of the pressure filter was assessed on sludges conditioned by either chemicals (lime and ferric chloride), polymers, flyash, or heat. All attempts to dewater polymer conditioned sludge proved to be totally unsuccessful due to rapid blinding of the filter media. Consequently, further evaluation of this type of conditioning was discontinued. An attempt was also made to thicken the digested sludge with polymers as a prelude to chemical conditioning in the hope that lower chemical requirements would result. However, such was not found to be the case.

The independent variables which control the operation of a pressure filter are the type of sludge conditioning, type of precoat, feed cycle time and feed pressure. All of these variables exert some influence on cake dryness, filtrate suspended solids and filter loading rate. Precoat of the filter is necessary to prevent blinding and insure that the cake can discharge cleanly. Diatomaceous earth and flyash are two materials which are suitable for this means. In this work, the type and amount of precoat was kept constant for each form of sludge conditioning studied. When the sludge was conditioned by chemicals or heat, diatomaceous earth was used for the precoat; with ash conditioning, ash was used for the precoat. Based on the manufacturer's recommendation, 4.5 lbs (2.0 kg) of precoat material was necessary for every 100 sq ft (9.3 sq m) of filter area. Preliminary tests indicated that a greater amount of precoat would not improve filtration rate or cake dryness, whereas an insufficient amount resulted in blinding of the filter media. Hence, the manufacturer's recommendation was closely adhered to in the test work.

The nature of the pressure filter operation required that feed pressure be increased with time to overcome the resistance from build-up of solids within the filter chamber. In this work, the pattern of pressure increase and length of time to progress from the initial pressure of 30 psig (2.1 kg/sq cm) to the final pressure of 220 psig (15.5 kg/sq cm) was kept constant for runs with each form of conditioning. With chemical and ash conditioning, this final pressure was allowed to be reached in 60 minutes in accordance with an increasing pressure pattern recommended by the manufacturer. Accordingly, pressure was increased in increments of 15 psi (1.1 kg/sq cm) every 5 minutes until 220 psig (15.5 kg/sq cm) was attained. This pressure was then maintained for the remainder of the run. For runs of less duration, maximum pressure was that obtained at the end of the feed cycle. Although this varied from the above procedure, it was done to simulate actual operating conditions. For heat conditioned sludge the formed floc proved to be more delicate than the chemically conditioned floc, resulting in rapid blinding of the filter. To overcome this, the length of time to reach maximum pressure was increased from 60 minutes to 100 minutes by lowering the incremental increase to 10 psi (0.7 kg/sq cm) every 5 minutes.

Operation of the pressure filter is such that, for all practical purposes, filtrate quality can be considered to be independent of conditioning and feed cycle time. The filter either works and produces an excellent filtrate or it blinds and produces no filtrate. With sufficient conditioning the filtrate usually contained less than 100 mg/l of suspended solids. Consequently, filtrate quality was not a major concern in evaluating the pressure filter nor in determining the operational criteria for its operation.

Since type and amount of precoat and feed pressure were essentially kept constant throughout the evaluation, only the conditioning and feed time were operational variables. Also, since filtrate quality was acceptable in all successful runs, cake dryness and loading rate became the only dependent variables. Of these, cake dryness was determined to be the more important.

The following general test procedure was used to evaluate the system. After the feed was pumped into the mix tank, grab samples of the feed were taken. One was taken without conditioning, and a second after conditioning. During the feed cycle, grab samples of the filtrate were collected every 15 minutes. From these samples one composite sample was taken. Determination of cake solids presented a problem. After inspecting the cakes from three chambers, their nonuniform solids content became apparent. All of the cakes were about the same consistency; however, the dryness of each cake increased with outward radial progression from the center core. To capture this variation in dryness three samples were taken as representative samples of each compartmentalized cake. An arithmetic average was used to represent the average cake solids.

A general analysis of the performance of the pressure filter can be made, regardless of the type of conditioning agents used. Based on this, the following was determined:

(1) From information obtained from published literature as well as from the manufacturer, it was expected that sludge dewatering characteristics would be better with higher concentrations of suspended solids in the feed material. This was generally found to be true when the sludge solids concentration was increased by gravity thickening or by addition of chemicals or flyash as a body feed material.

(2) Visual inspection of the feed sludge revealed that a large portion of the solids consisted of fine particles. For effective filtration to occur, good coagulation of these fine particles was necessary. In the case of heat conditioned sludge this would be accomplished by gravity thickening of the portrate; for chemical or ash conditioned sludge, coagulation would be induced by maintaining a high pH. A pH of around 10 is usually necessary for

good coagulation of colloidal particles. For coagulation of the fines in the JWPCP's sludge, a pH of 11.5 was found to be necessary. Consequently, the amount of lime added to the feed sludge was based on the requirement of raising the pH to promote good coagulation.

(3) In spite of the pattern used for increasing the operating pressure to overcome resistance from solids accumulation within the filter, there was a rapid decrease in the instantaneous flowrate through the unit. Thus, the solids loading rate became lower as the duration of the feed cycle progressed.

(4) Increasing the feed cycle promoted compression of the accumulated solids within the press and, hence, increased cake dryness. Therefore, there existed an inherent trade-off in the operation of the pressure filter between cake solids and loading rate, i.e. the drier the cake, the lower the solids loading rate.

Data summarizing test results on the pilot plant pressure filter under variable feed cycles with various lime and ferric chloride dosages are presented in Table 35. For a constant lime dosage of 400 lbs/ton (200 kg/metric ton) as $Ca(OH)_2$, the effect of feed time on the solids content of generated cakes at each of several ferric chloride dosages is shown in Figure 38. The same effect is shown in Figure 39 for a constant lime dosage of 500 lbs/ton (250 kg/metric ton) as $Ca(OH)_2$. The plotted results in both figures indicate that regardless of the feed time, drier cakes are obtained with increased ferric chloride dosage up to 120 lbs/ton (60 kg/metric ton). Ferric chloride dosages greater than this were not considered due to its corrosive properties and its adverse tendency to lower the pH of the system. A comparison of Figures 38 and 39 reveals that generated cakes were driest when the higher lime dosage was used. The curves also reveal that, beyond a feed cycle of 2 hours, cake dryness does not increase significantly. A plot of loading rate versus feed time is presented in Figure 40 for the situation when the lime and ferric chloride dosage was held constant at 500 lbs/ton (250 kg/metric ton) as $Ca(OH)_2$ and 120 lbs/ton (60 kg/metric ton), respectively. From this it is seen that the loading rate decreased rapidly as

Table 35: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF CHEMICALLY CONDITIONED DIGESTED SLUDGE IN A PRESSURE FILTER

PARAMETERS

1. Filter:..... Beloit-Passavant pressure filter
2. Pressure:... Initial @ 30 psig (2.1 kg/sq cm);
   maximum @ 220 psig (15.5 kg/sq cm)
3. Precoat:.... Diatomaceous earth

CHEMICAL DOSAGE		FEED	SUSPENDED SOLIDS CONCENTRATION			TOTAL	CALCULATED
$FeCl_3$ -lbs/ton-	Lime as $Ca(OH)_2$ -lbs/ton-	CYCLE TIME -hr-	Sludge Feed** -%-	Filtrate*** -%-	Filter Cake -%-	FLOW -gal.-	SOLIDS LOADING** -lbs/hr/sq ft-
80	400	1.0	3.57	.008	23.3	-	-
		2.0	3.55	.001	29.0	72	0.59
		3.0	3.77	.001	30.1	70	0.41
	600	0.5	3.60	.005	25.7	54	1.80
		2.0	3.85	.004	36.0	98	0.87
		3.0	3.56	.005	39.2	120	0.62
100	400	0.5	4.02	.004	21.1	36	1.42
		1.5	3.64	.003	29.9	96	1.08
		2.0	3.50	.001	31.1	83	0.45
		3.0	3.64	.003	33.0	-	-
	500	0.75	4.07	.001	28.5	67	1.68
		1.0	4.17	.001	30.4	82	1.60
		2.0	3.58	.001	36.8	97	0.80
		3.0	3.24	.009	38.2	122	0.61
120	400	0.5	3.53	.001	21.1	41	1.33
		1.0	3.32	.003	29.0	60	0.98
		2.0	3.60	.001	35.1	92	0.78
		2.5	3.30	.002	35.7	114	0.70
	500	0.5	3.98	.001	27.9	70	2.58
		0.75	4.01	.001	32.2	63	1.57
		1.5	3.64	.001	38.8	67	0.75
		3.0	4.01	.004	41.0	108	0.66

*All data pertain to filtration studies on JWPCP primary digested sludge.

**Not corrected for the addition of $FeCl_3$ and lime.

***Data are indicative of suspended solid captures in excess of 99 percent.

Unit Conversions:

(gal) x 3.785 = (liters)
(lbs/ton) x 0.5 = (kg/metric ton)
(lb/hr/sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/l)

FIGURE 38

The effect of feed time on cake solids during pressure filtration of digested sludge

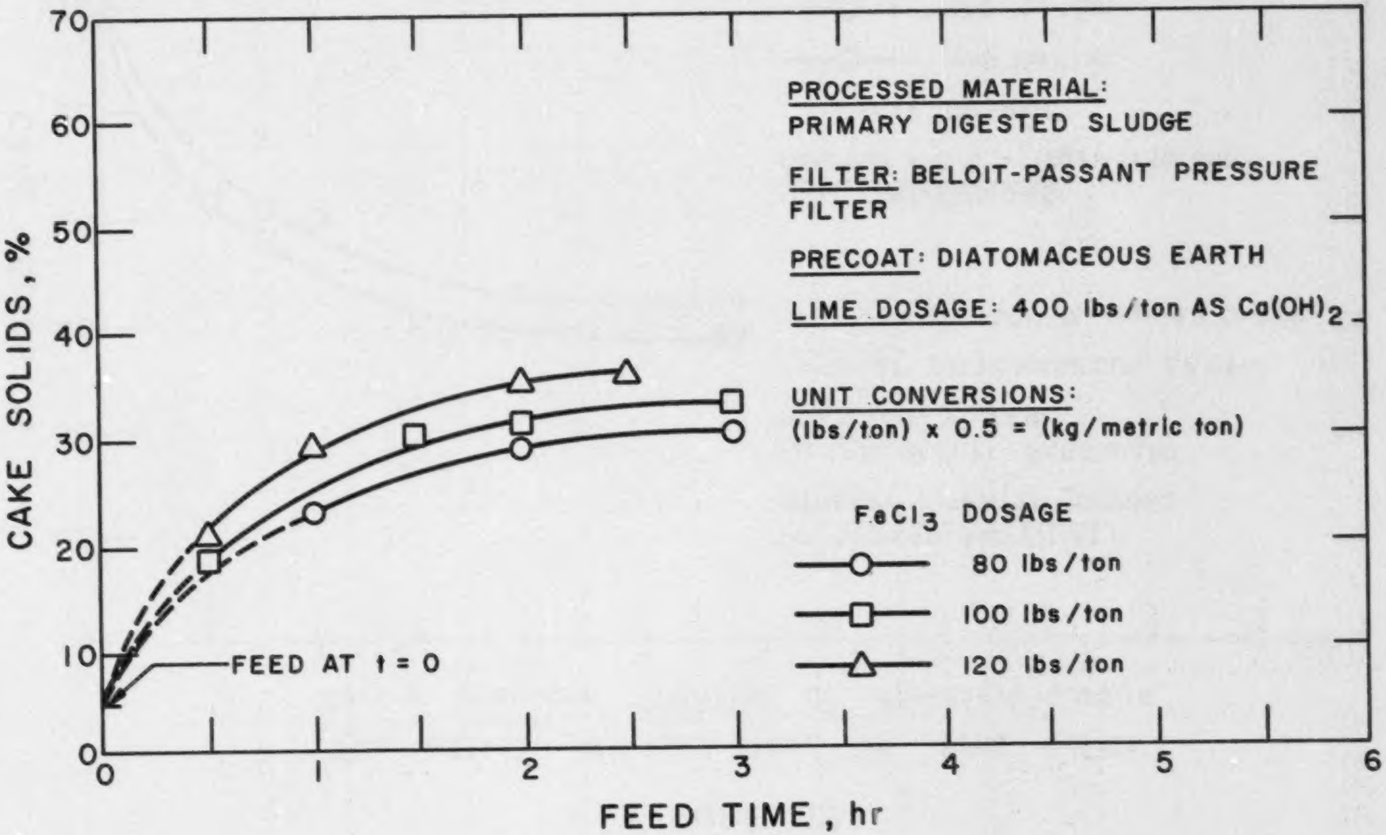


FIGURE 39

The effect of feed time on cake solids during pressure filtration of digested sludge

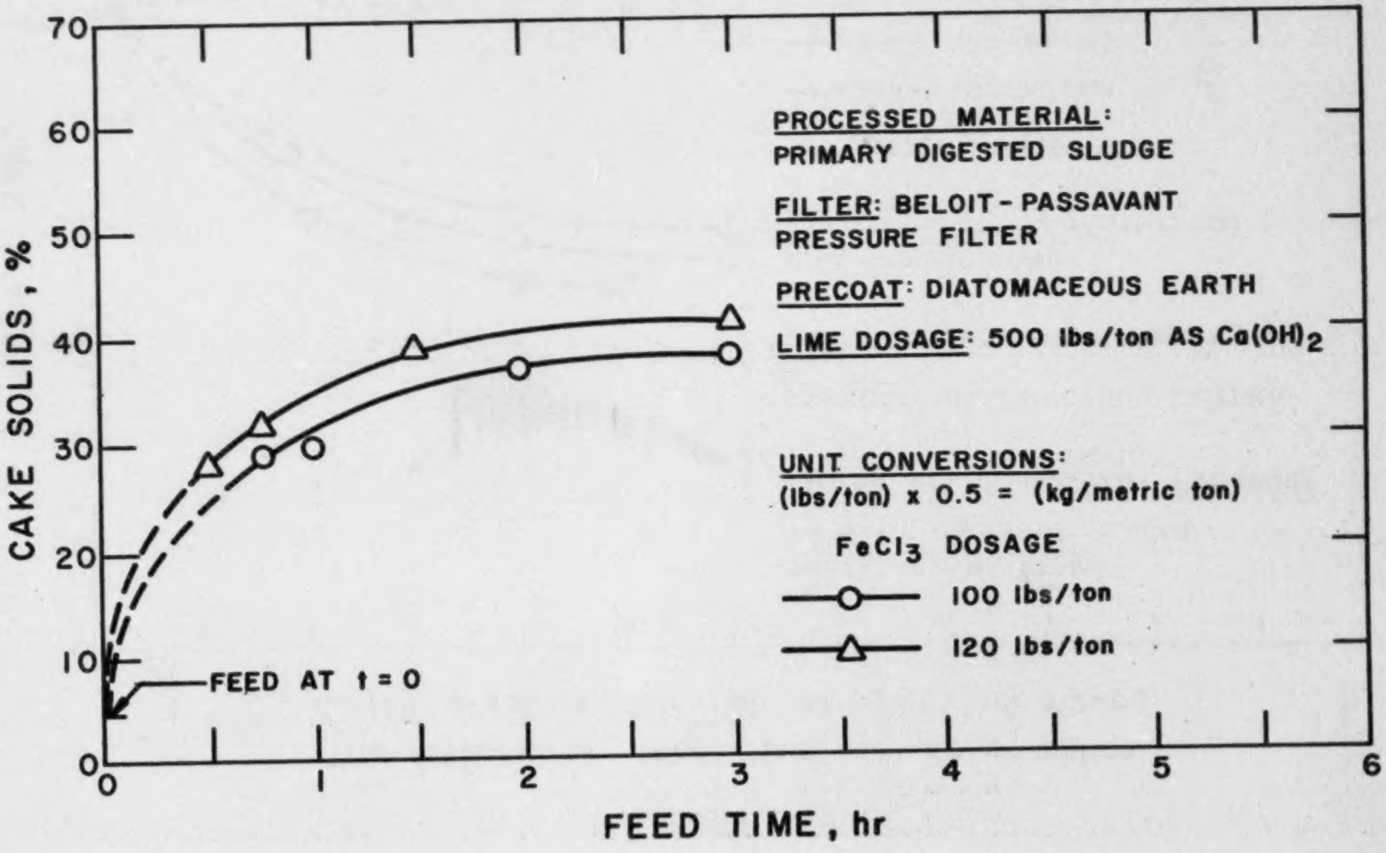
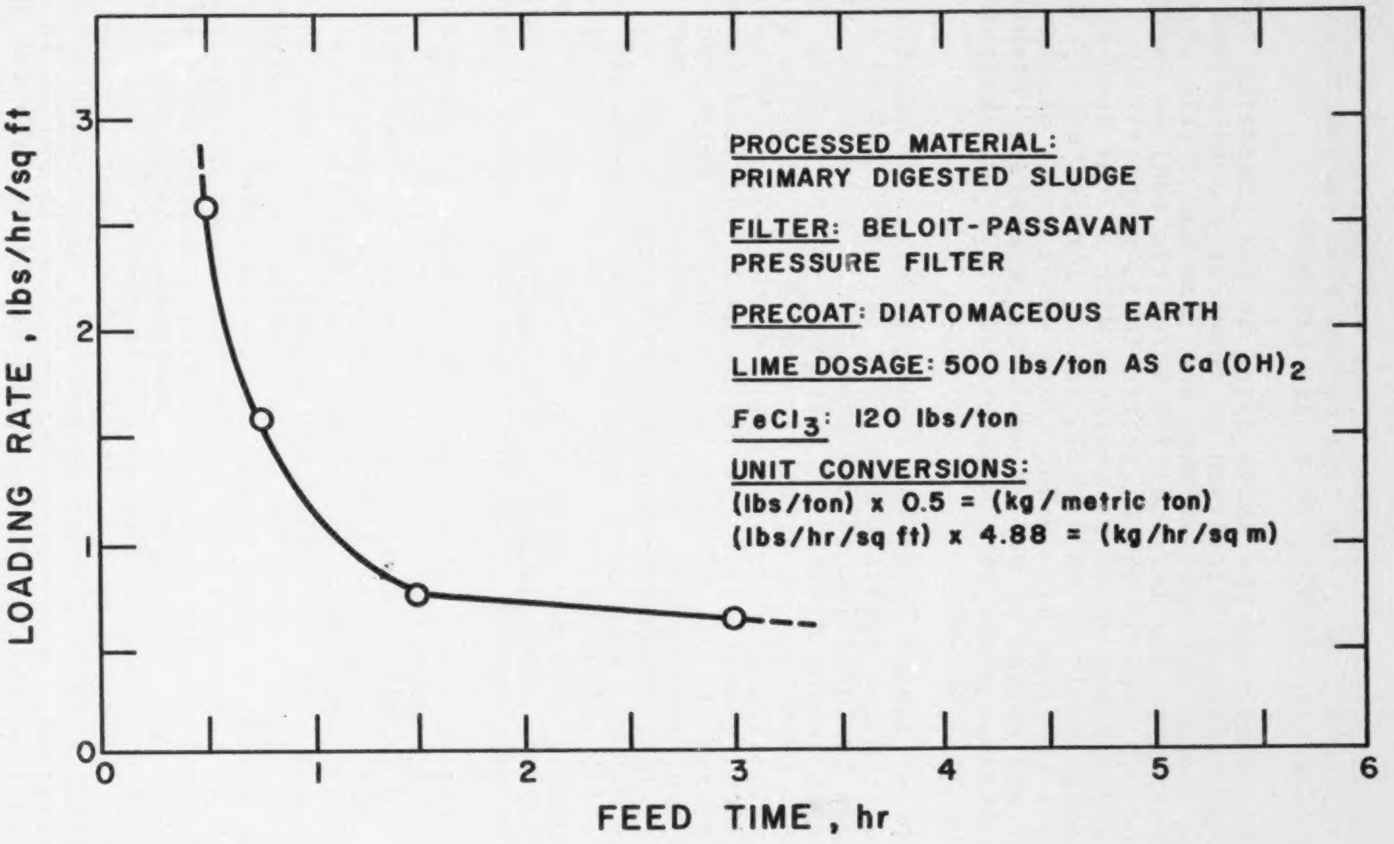


FIGURE 40

Loading rate as a function of feed time during pressure filtration of chemically conditioned digested sludge



the duration of the feed cycle was increased to 1.5 hours. Increased feed cycle time beyond this served to reduce the overall loading rate only slightly.

Upon analyzing the above data, it was generally felt that pressure filtration of chemically conditioned digested sludge was optimum when the lime and ferric chloride dosage was 500 lbs/ton (250 kg/metric ton) as $Ca(OH)_2$ and 120 lbs/ton (60 kg/metric ton), respectively. Optimum cake dryness would be achieved with a 2-hr feed cycle and would result in an overall solids loading of 0.7 lbs/hr/sq ft (3.4 kg/hr/sq m). Under these conditions, discharge cakes of 40% solids by weight would be generated. Resulting filtrates would have a suspended solids concentration of 100 mg/l or less.

Flyash conditioning was investigated as an alternative to chemical conditioning. The use of flyash is dependent upon incineration of the produced cake to obtain the ash conditioning material. Results from the testing of flyash as a conditioning agent are summarized in Table 36. Initially, studies were carried out using 2000 lbs/ton (1000 kg/metric ton) of flyash as a body feed material. Without the use of lime, a 37% cake was generated in a 2-hour feed cycle; the solids loading rate, however, was low. When 450 lbs/ton (225 kg/metric ton) of lime as $Ca(OH)_2$ was added, generated cake dryness was increased to 47% solids weight. More importantly, the solids loading rate and total flow through the filter almost tripled. This indicated the importance of lime addition for raising the pH of the flyash conditioned sludge.

Tests were run to determine the effects of increasing the ash dosage to 3000 and 4000 lbs/ton (1500 and 2000 kg/metric ton). For runs under similar conditions, conditioning with 4000 lbs/ton (2000 kg/metric ton) of flyash produced a drier cake than with the lower ash dosage. At the higher ash dosage, an increase in the feed cycle time effected an increase in cake dryness. As noted, a small amount of lime was used to raise the pH of the conditioned sludge and induce coagulation. Following a one-hour feed cycle, a discharged cake of 43% solids by weight was generated. As noted, an actual sludge solids loading of 0.5 lbs/hr/sq ft (2.4 kg/hr/sq m) was experienced. Increasing the feed cycle to 3 hours served only to increase cake dryness slightly. A corresponding reduction in solids loading was also effected. While the resulting cake was about

Table 36: DATA* SUMMARIZING THE EFFECTS OF ASH AND LIME ADDITION TO DIGESTED SLUDGE ON DEWATERING PERFORMANCE IN A PRESSURE FILTER

PARAMETERS

1. Filter:..... Beloit-Passavant pressure filter
2. Pressure:... Initial @ 30 psig (2.1 kg/sq cm) to maximum @ 220 psig (15.5 kg/sq cm)
3. Precoat:.... Diatomaceous earth
4. Flyash:..... Pulverized ash residue from BSP mutliple hearth pilot plant furnace

ASH DOSAGE -lbs/ton-	LIME DOSAGE as $Ca(OH)_2$ -lbs/ton-	FEED CYCLE TIME -hr-	SUSPENDED SOLIDS CONCENTRATION Sludge Feed** -%-	Filtrate*** -%-	Filter Cake -%-	TOTAL FLOW -gal-	CALCULATED SOLIDS LOADING** -lbs/hr/sq ft-
2000	0	2.0	4.12	0.004	36.6	23	0.23
	450		3.60	0.003	47.2	54	0.60
3000	50	2.0	3.62	0.003	45.1	51	0.43
	100		3.67	0.005	43.0	37	0.38
4000	150	1.0	3.53	0.012	43.2	31	0.50
		2.0	3.53	0.008	47.1	43	0.35
		3.0	3.50	0.008	49.6	50	0.27

*All data pertain to filtration studies on JWPCP primary digested sludge.

**Not corrected for the addition of ash and lime.

***Data are indicative of suspended solid captures in excess of 99 percent.

Unit Conversions:

(gal) x 3.785 = (liters)
(lbs/ton) x 0.5 = (kg/metric ton)
(lb/hr/sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/l)

50% solids by weight, consideration was also given to the fact that two-thirds of the solids were recycled ash. Further analysis revealed that the ratio of water to sludge solids in that cake was the same as that optimally obtained with chemical conditioning.

With regards to heat conditioning, the dewatering characteristics of the pressure filter on both thickened and unthickened portrate were looked at briefly. The results of these tests are summarized in Table 37. Through heat conditioning, the suspended solids in the feed are reduced to 2.5% (25,000 mg/l). Because of the low feed solids a longer feed time is needed to dewater the unthickened sludge and form a dry cake. Typical results showed that a 2-to 3-hour feed time was necessary to generate a cake of 30% solids by weight. Cake discharge from the opened plates, however, was poor. Solids loadings to the filter reached an optimum of 0.59 lb/hr/sq ft (2.9 kg/hr/sq m). Filtrate quality was again excellent, with essentially 100% suspended solids removal from the system. For comparison, a 2-hour filtration run was carried out using thickened portrate for feed material. Cake solids were at 38% by weight and the corresponding filtrate was of excellent quality. The solids loading for the run was calculated to be 1.05 lbs/hr/sq ft (5.1 kg/hr/sq m).

It was obvious from the above that some benefits did prevail by the inclusion of the intermediate thickening step into the system. Drier cakes with superior discharge properties were obtained in a shorter period of operating time. Also, solid loadings to the filter were nearly doubled. These benefits, however, were offset by sacrifices in overall effluent quality. Though filtrate quality remained unaffected, consideration was given to the decanted overflow from the thickening clarifier. A combined filtrate-decant effluent would contain about 0.32% (3200 mg/l) suspended solids. Hence, an overall suspended solids removal of 92 percent would be possible from such a system.

Attempts to evaluate the dewatering capabilities of the diaphragm press were, for the most part, unsuccessful. The relatively small size of the feed system to the unit made it impossible to inject most of the conditioned digested sludges into the filtration chamber. Some success was realized with unthickened portrate (probably because of the low suspended solids content of that material). However, attempted runs were of such short duration that

Table 37: DATA* SUMMARIZING THE DEWATERING CHARACTERISTICS OF UNTHICKENED AND THICKENED HEAT-CONDITIONED DIGESTED SLUDGE BY PRESSURE FILTRATION

PARAMETERS
1. Processed Material:........ JWPCP primary digested sludge
2. Porteous Conditioning:..... 40 min @ 350°F (175°C)
3. Thickener Overflow Rate:... 225 gpd/sq ft (9.2 cu m/day/sq m)
4. Filter:.................... Beloit-Passavant pressure filter
5. Pressure:.................. Initial @ 30 psig (2.1 kg/sq cm); Maximum @ 220 psig (15.5 kg/sq cm)
6. Precoat:................... Diatomaceous earth

WITH AND WITHOUT THICKENING	FEED CYCLE TIME -hr-	SUSPENDED SOLIDS CONCENTRATION			TOTAL FLOW -gal.-	CALCULATED SOLIDS LOADING** -lbs/hr/sq ft	SUSPENDED SOLIDS IN EFFLUENT BLEND (Decantate + Filtrate) -%-	TOTAL SUSPENDED SOLIDS REMOVAL BY SYSTEM** -%-
		Sludge Feed -%-	Filtrate -%-	Filter Cake -%-				
Without	2.0	3.46	0.010	33.8	63	0.50		99.7
	2.5	2.41	0.002	30.2	118	0.52		99.9
	3.0	2.69	0.004	30.0	119	0.59		99.9
With	2.0	11.32	0.004	38.1	37	1.05	0.31	92.0

*All data pertain to tests conducted on JWPCP primary digested sludge.

**Removal by 'System' includes filter capture, thermal volatization, and thermal transfer to the dissolved phase. Calculated values are based on a suspended solids concentration of 3.5% in the digested sludge fed to the system.

Unit Conversions:
(gal.) x 3.785 = (liters)
(lbs/hr/sq ft) x 4.88 = (kg/hr/sq m)
(% Solids) x 10,000 = (mg/l)

numerical assessment of the unit's capabilities was not possible. Visually, its performance looked promising though. Filtrates were of excellent quality (less than 100 mg/l of suspended solids). Resultant cakes were at 30% solids by weight but were extremely thin and, as a consequence, would not discharge from the filter media. It was generally felt, however, that minor changes in the unit's design would greatly enhance its capabilities for future application.

SUMMARY DISCUSSION OF TEST WORK

Thermal conditioning of the JWPCP's digested sludge was dependent on sludge cooking time and the associated cooking temperature. A temperature of 360°F (180°C) was required if sludge was to be cooked for only 30 minutes. Allowing 40 minutes of cooking time enabled the required cooking temperature to be reduced to 350°F (175°C). In terms of solids settleability, optimum conditioning of digested sludge occurred under the latter set of operating conditions. This, therefore, became the manner in which portrate was prepared for use in evaluating other processing equipment.

Optimum performance of the picket thickening clarifier occurred when the feedrate to the unit was lowest. Accordingly, this corresponded to an overflow rate of 225 gpd/sq ft (9.2 cu m/day/sq m). Depending on the concentration of suspended solids in the fed portrate and the allowed thickening time, sludge thickening in the range of 6-12% (60,000-120,000 mg/l) suspended solids was possible. Decanted overflow from the thickener contained about 3700 mg/l of suspended material.

Data, comparatively summarizing the OPTIMUM performance of various sludge conditioning-dewatering systems investigated at the JWPCP, are presented in Table 38. Reference is made to the previous text for a more detailed presentation and discussion of the work with each system.

Test work conducted on a full scale 36-inch x 96-inch (91.4-cm x 243.8-cm) Bird centrifuge revealed that, without any form of sludge conditioning, the maximum solids recovery obtainable was about 55 percent. This was accomplished at a sludge feedrate of 200 gpm (12.6 l/sec) while centrifuging at 900 G's with the pool depth set to the 3.4-inch (8.6-cm) maximum. Generated cake solids were 21% by weight. Cationic polymer conditioning enhanced

Table 38: DATA SUMMARIZING THE OPTIMUM PERFORMANCE OF VARIOUS INVESTIGATED SLUDGE CONDITIONING AND DEWATERING SYSTEMS AT JWPCP

PARAMETERS

1. Heat Treatment:............ 40 min @ 350°F (175°C)
2. Thickener overflow rate:... 225 gpd/sq ft (9.2 cu m/day/sq m)
3. Polymer:.................. Cationic
4. Chemicals:................ Ferric Chloride and/or Lime

DEWATERING SYSTEM	CONDITIONING** AND PRELIMINARY PROCESSING	SUSPENDED SOLIDS CONTENT		SUSPENDED SOLIDS REMOVAL FROM SYSTEM -%-
		Effluent from System -%-	Dewatered Cake Solids -%-	
Horizontal Scroll Centrifuge	1.None	1.86	21	55
	2.Polymer(10 lbs/ton)	0.15(1)	20	95
	3.Heat	0.73	31	81
	4.Heat + polymer(3.5 lbs/ton)	0.38	31	90
	5.Heat + thickening	0.61	25	85
	6.Heat + thickening + polymer(3 lbs/ton)	0.34	25	91
Basket Centrifuge (2nd Stage)	1.Horizontal Scroll Centrifugation	0.50	12	89
	2.Horizontal Scroll Centrifugation + polymer (4 lbs/ton) to 2nd stage	0.15	25	95
Vacuum Coil Filter	1.Polymer (10 lbs/ton)	0.15	18	95
	2.$FeCl_3$ & Lime (80 & 600 lbs/ton)	0.25	26	92(3)
	3.Heat + Thickening	1.08	31	70
Rotary-Belt Vacuum Filter	1.Polymer (10 lbs/ton)	0.04	18(2)	99
	2.Lime (600 lbs/ton)	0.02	35	99+
	3.Heat + thickening	0.32	36	92
Vacuum Extractor	1.Heat + thickening	0.44	35	89
Pressure Filter	1.$FeCl_3$ & Lime (120 & 500 lbs/ton)	0.01	40	99+
	2.Heat	0.01	30(2)	99+
	3.Heat + Thickening	0.31	38	92
	4.Ash (4000 lbs/ton) & Lime	0.01	47	99+
Diaphragm Press	1.Heat	0.01	30(2)	99+

(1) Not consistently obtainable (2) Poor Cake Discharge (3) Low Loading

* All data pertain to tests conducted on JWPCP digested sludge.

** Lime dosages are expressed in terms of $Ca(OH)_2$.

Unit Conversions: (lbs/ton) x 0.5 = (kg/metric ton)
(% Solids) x 10,000 = (mg/l)

the centrifugal capture of suspended solids. Several different polymer products were tested in this regard. All tests were conducted under the same machine operating conditions stated above. The sludge feedrate was held constant at 250 gpm (15.8 l/sec). Polymer solutions were added by bowl injection. While the performance of each polymer was slightly different from one another, it was generally concluded that to obtain a centrate of 1500 mg/l or less (95 percent capture), a polymer dosage of 10 lbs/ton (5.0 kg/metric ton) was required. This performance was also found to be unpredictable on a day-to-day basis due to changing characteristics in the sludge feed material. Resulting centrifuged cakes were about 20% solids by weight -- a value somewhat lower than desired but copeable should the system be economically justified.

Heat conditioning, with or without intermediate portrate thickening, provided some enhancement for sludge solids dewatering in a horizontal scroll centrifuge. However, the experienced recoveries (85 and 81 percent, respectively) were deemed to be insufficient for meeting the WQCB standards placed on the JWPCP. The addition of 3.0-3.5 lbs/ton (1.50-1.75 kg/metric ton) of cationic polymer to either the unthickened or thickened portrate streams within the centrifuge bowl enabled overall suspended solids removals of 90-91 percent to be achieved. No effect was seen on the discharge cakes. The fact that wetter cakes were obtained when intermediate thickening was employed is attributable to the increased solids loading to the centrifuge; lower throughput rates of thickened portrate would probably have effected drier cakes but were not investigated. On a full scale basis, the effluent from such a system would require some form of biological treatment due to the high soluble BOD component (estimated at 5000 mg/l). Although additional solids removal would likely occur to meet the standards, the required conditioning (heat conditioning plus polymer addition) would render the systems economically unattractive.

Without the usage of polymers, basket centrifugation of Bird centrate would be inadequate for meeting the WQCB standards. Also, the 12% cakes (resulting from a blend of those derived from the first and second stage) would require additional dewatering to render them handleable. Polymer addition to Bird centrate within the bowl of the basket centrifuge was found to enhance solids capture and cake dryness. Cake solids of 20-22% by weight were obtained from the second stage with a polymer dosage of

4 lbs/ton (2.0 kg/metric ton). Based on the suspended solids contained in the JWPCP's digested sludge, this corresponded to a system polymer dosage of less than 3 lbs/ton (1.5 kg/metric ton). Overall solid captures would be such that the resulting effluent would contain about 1500 mg/l of suspended material. A blend of first and second stage generated cakes would result in one having an average solids content of 25% by weight. Noteworthy is the fact that the cakes derived from basket centrifugation were easily handled on a belt conveyor inclined at 30° from the horizontal.

Coil filtration of the JWPCP primary digested sludge was best when polymers were used as the conditioning aid. A dosage of about 10 lbs/ton (5.0 kg/metric ton) was required to consistently produce a filtrate having an average suspended solids concentration of 1500 mg/l. This performance was obtainable with loading rates up to 18 lbs/hr/sq ft (87.8 kg/hr/sq m). Generated filter cakes were about 18% solids by weight and remained unchanged with longer dry cycles at reduced belt speeds. As in horizontal scroll centrifugation with polymer addition, the wet cakes were attributable to the bound water associated with the higher percentage of fines in the captured solids. Though drier cakes would be more desireable, it was generally felt that those from the coil filter would be manageable. Drier cakes were obtainable when lime and ferric chloride were used as the conditioning aid. Suspended solids captures were maximized at 92 percent recovery with a lime as $Ca(OH)_2$ and ferric chloride dosage of 600 and 80 lbs/ton (300 and 40 kg/metric ton), respectively, in combination with a solids loading rate of 1.6 lbs/hr/sq ft (7.8 kg/hr/sq m). In comparison to the 18 lbs/hr/sq ft (87.8 kg/hr/sq m) attainable with polymer usage, this low loading would render such a sludge handling system economically undesirable in spite of the better quality cakes (26% solids by weight) obtained. Coil filtration of thickened heat-conditioned digested sludge produced the driest coil-filter cakes (31% solids by weight). Unfortunately, suspended solid removals (70 percent) were the lowest compared to any of the other systems listed in Table 38. A further drawback was the low loading rate of 3 lbs/hr/sq ft (14.6 kg/hr/sq m) necessary to achieve these results. The poor performance experienced with this latter system was ascribed to the porous nature of the coil spring media.

Although solid recoveries of 99 percent were obtained by rotary-belt vacuum filtration of polymer conditioned digested sludge, generated filter cakes were thin and wet (18% solids by weight) and discharged poorly from the unit. Consequently, the system was eliminated for further consideration. Similar captures were achieved when lime was used as the conditioning agent. Optimum results were achieved at a lime dosage of 600 lbs/ton (300 kg/metric ton) as $Ca(OH)_2$ while operating at a loading rate of 1.5 lbs/hr/sq ft (7.3 kg/hr/sq m) to the unit equipped with a Polypropylene 854-F cloth belt. The inclusion of ferric chloride did not add or detract from this situation. Yielded filtrates contained approximately 200 mg/l of suspended material. Filter cakes (35% solids by weight) were excellent and discharged freely and completely from the belt. Somewhat higher loadings and drier cakes were attained when subjecting thickened heat-conditioned digested sludge to rotary-belt vacuum filtration. As with lime addition, best performance was experienced with the Polypropylene 854-F belt media. Generated cakes of 36% solids by weight discharged freely and completely from the unit at a solids loading up to 3.3 lbs/hr/sq ft (16.1 kg/hr/sq m). Filter capture was such that the resulting filtrate contained about 1300 mg/l of suspended solids. However, a blend of this effluent with the decantate from the thickener would result in a system effluent containing 3200 mg/l of suspended material. Overall, this would correspond to suspended solid removals of 92 percent -- a value which includes filter capture, thermal volatization and thermal transfer to the dissolved phase. Upon subjection of this effluent to biological treatment (required for soluble BOD reduction), additional removals would likely be effected to render it acceptable for primary effluent blending and ocean discharge.

As with rotary-belt vacuum filtration, vacuum extraction (horizontal-belt filtration) of heat-conditioned digested sludge was only possible with the incorporation of the intermediate thickening step. Generated cakes were 35% solids by weight but were thin and discharged somewhat poorly. This result was attained at a loading rate of 2.7 lbs/hr/sq ft (13.2 kg/hr/sq m) -- a rate drastically below that normally encountered for such an operation.

From the standpoint of effluent quality, the best performing system was that utilizing pressure filtration in conjunction with either chemical, ash or thermal conditioning. With chemical conditioning, optimum results obtained by analysis of all the data indicated that a 40% cake would be produced in a 2-hour feed cycle time utilizing lime and ferric chloride dosages of 500 lbs/ton (250 kg/metric ton) as $Ca(OH)_2$ and 120 lbs/ton (60 kg/metric ton), respectively. Under these conditions, solids loading (excluding the contribution of the conditioning aids) over the feed period would be about 0.7 lbs/hr/sq ft (3.4 kg/hr/sq m); yielded filtrates would contain less than 100 mg/l of suspended material. Similar filtrates were obtained when ash was used as the conditioning aid. Best results were achieved when 2 lbs (0.90 kg) of ash were added per one pound (0.45 kg) of sludge solids. In addition, 100-150 lbs/ton (50-75 kg/metric ton) of lime as $Ca(OH)_2$ was required to raise the pH of the sludge. A 2-hour feed cycle under these conditions yielded cakes of 47% solids by weight. But since two-thirds of the solids were flyash, the actual sludge solids loading during the cycle was only 0.35 lbs/hr/sq ft (1.7 kg/hr/sq m), i.e. exactly half that obtained with ferric chloride and lime conditioning. Analysis also indicated that the ratio of water to sludge solids in the cake would be the same as that in the 30% cakes produced with chemical conditioning. Pressure filtration of heat-conditioned digested sludge (without thickening) also produced filtrates containing less than 100 mg/l of suspended solids. Generated cakes (30% solids by weight) were certainly acceptable, though a 2.5-hour feed cycle time was required to produce them. Under this type of operation, a sludge solids loading of about 0.52 lbs/hr/sq ft (2.5 kg/hr/sq m) would only be possible. The incorporation of an intermediate portrate thickening step served to eliminate the fines, thereby allowing solids loadings of 1.05 lbs/hr/sq ft (5.1 kg/hr/sq m) to be experienced. Filter cakes of 38% solids by weight were produced during 2-hour feed cycles. Produced filtrates contained less than 100 mg/l of suspended material but served only to dilute the decantate to a resultant effluent having 3200 mg/l of suspended material. Based on 3.5% (35,000 mg/l) suspended solids in the JWPCP's digested sludge, this corresponded to an overall suspended solids removal of 92 percent. Considering the equipment involved in the various pressure filtration alternatives just discussed, the operation with chemical conditioning had the appearance of being most economical. Usage of polymers was not a considered alternative since rapid blinding of the pressure filter media resulted when polymer conditioning was attempted.

Attempts to dewater unthickened heat-conditioned digested sludge in a diaphragm press were somewhat discouraging. Although yielded filtrates contained less than 100 mg/l of suspended material, rapid blinding of the filter media was encountered, thus resulting in feed cycles of short duration and little cake buildup. Hence, the thin generated cakes (30% solids by weight) discharged poorly. Because of the experimental setup, it was not possible to pressure feed thickened portrate into the unit. Dewatering tests in conjunction with other forms of conditioning were not conducted.

In summary, the pilot plant research on the dewatering of the JWPCP primary digested sludge produced five schemes capable of dewatering to the extent necessary to allow the WQCB discharge standards to be met. These are sumarized in Table 39. With the exception of the thermal-thickening-vacuum filter scheme, all of these systems produced an effluent suspended solids of 1500 mg/l or less; based on a limited number of BOD tests run on the various filtrate and centrate effluents, the resulting BOD of these four systems would be 1000 mg/l or less. By subjecting the effluent from the thermal-thickening-filtration scheme to biological treatment, the tabulated suspended solids and BOD would be reduced to 500 mg/l and 1000 mg/l, respectively, thus falling within the above discussed levels. On a full-scale basis, the 1.8 mgd (6800 cu m/day) of effluent from any system would be diluted approximately 200-to-one when combined with the 380 mgd (1.43 million cu m/day) of primary effluent. Hence, the anticipated concentrations of suspended solids and BOD from any dewatering system effluent would, at most, add 7.5 mg/l of suspended solids and 2.5 mg/l of BOD to the combined plant discharge.

All of the five selected schemes which met the desired end result required some form of sludge conditioning, i.e. polymers, chemical or heat. Cakes resulting from the five systems varied in solids content from 18% to 40% by weight. Of the five systems, one would allow continued use of the existing horizontal scroll centrifuges.

Table 39: PERFORMANCE SUMMARY* OF FIVE SELECTED DEWATERING SCHEMES HAVING FULL-SCALE POTENTIAL FOR MEETING THE IMPOSED DISCHARGE STANDARDS

DEWATERING SYSTEM	TYPE OF CONDITIONING	CHEMICAL OR POLYMER DOSAGE -lbs/ton-	EFFLUENT SUSPENDED SOLIDS -mg/1-	EFFLUENT BOD -mg/1-	CAKE SOLIDS -%-
Two-Stage Centrifugation (Horizontal Scroll + Basket)	Cationic Polymer to 2nd Stage Basket Centrifuge	3	1500	1000	25
Vacuum Coil Filtration	Cationic Polymer	10	1500	1000	18
Rotary-Belt Vacuum Filtration	Lime as $Ca(OH)_2$	600	200	500	35
	Heat Treatment and Picket Thickening**		3200***	5000***	36
Pressure Filtration	Lime as $Ca(OH)_2$ Ferric Chloride	500 120	100	200	40

*Tabulated data pertain to performance results obtained from pilot plant tests on JWPCP digested sludge.

**Porteous conditioning for 40 minutes @ 350°F (175°C) with followup thickening; thickner overflow rate @ 225 gpd/sq ft (9.2 cu m/day/sq m).

***Biological treatment of effluent will reduce suspended solids and BOD concentrations to 500 mg/1 and 1000 mg/1, respectively.

Unit Conversions: (lbs/ton) x 0.5 = (kg/metric ton)

COST ESTIMATES

Having determined the performance of all combinations of conditioning and dewatering systems tested at the JWPCP and concluding that five of these schemes would enable the effluent discharge requirements to be met, cost estimates were prepared to provide a rationale for selecting a full scale process. These included:

1. Capital and operating costs for the five selected dewatering systems.
2. Ultimate disposal costs by two methods, namely
    - (a) Landfilling, with transport of the sludge either by truck (in a dewatered condition) or by pipeline with dewatering at the landfill.
    - (b) Incineration, with ash hauling to the landfill.

The costs of dewatering and disposal were combined to provide an estimate of the cost for a total system. In addition, a brief study was made of the prospective costs associated with remote disposal of digested sludge. These latter estimates were made to aid in selecting a dewatering process that would be compatible with some future scheme of ultimate sludge disposal to a remote area.

The data used in preparing the dewatering-disposal costs were derived from several sources. Equipment manufacturers provided estimates of their respective equipment costs along with recommendations regarding power, labor, maintenance and standby equipment. Hourly labor costs were obtained from records associated with the operation of the existing centrifuge station at the JWPCP. Site preparation, building, conveyor and engineering costs, etc. were estimated with the assistance of the Districts' Design Division. Truck hauling and landfill disposal costs were obtained with the aid of the District's

Refuse Department; truck hauling times were estimated from records secured through previous experience in hauling sludge from the JWPCP to a landfill.

Because the data for the estimates were obtained from various sources, every effort was made to be consistent with respect to the common factors used in each estimate. The assumption was made that the hourly labor charge would be the same for every system. Also, the same unit cost was used for whatever power, polymers and chemicals were required in each scheme. Moreover, it was assumed that all dewatering systems, including truck loading facilities for hauling, would be housed within a building.

Since the purpose of the cost estimates was to provide a method of comparing various processes, the costs for components which were common to all alternatives, i.e. wet wells pumps, influent and effluent piping, etc., were not included. For similar reasons, the volumetric quantity of digested sludge to be handled was placed at 2 mgd (7500 cu m/day) -- an amount slightly in excess of present day production. Based on 3.8% suspended solids concentration and 95 percent solids capture, the quantity of sludge to be dewatered would therefore be about 300 dry tons (272 metric tons) per day. No attempt was made to provide estimates of future sludge quantities and handling costs for the useful life of the dewatering system.

DEWATERING COSTS FOR TWO-STAGE CENTRIFUGATION

The cost estimate for a two-stage centrifugation system is shown in Table 40. It was assumed that the existing horizontal scroll centrifuges would continue to operate in their present manner; hence, no capital expenditures were estimated for that part of the system. The parameters used in making up the capital cost estimate were as follows:

(1) Polymer dosage........... 800 lbs/day (360 kg/day) to the second stage component

(2) Building area required.... 20,000 sq ft (1860 sq m) for housing both stages.

Table 40: COST ESTIMATE SUMMARY FOR TWO-STAGE CENTRIFUGATION

CONDITIONS

1. Sludge conditioning:......... polymer dosage of 4 lb/ton (2 kg/metric ton) to second stage centrifuge
2. Centrate suspended solids:... 1500 mg/l
3. Cake solids:................. 25% solids by weight (blend of cakes from each stage)

CAPITAL COST

1. Basket centrifuges - installed	$1,450,000
2. Polymer storage and feed system - installed	70,000
3. Conveyor - 300 ft (90 m)	35,000
4. Building - 20,000 sq ft (1860 sq m), installed	300,000
5. Contractor - (10% of items 1 & 2)	150,000
6. Contingencies	340,000
7. Engineering - flat fee	500,000
Total Capital Cost	$2,895,000

OPERATION & MAINTENANCE COST

1. Labor	$ 44,000/yr
2. Power	82,000/yr
3. Water	6,000/yr
4. Maintenance materials	30,000/yr
5. Polymers	290,000/yr
6. First stage operating cost	360,000/yr
Total Operation & Maintenance Cost	$ 812,000/yr

Results of the research work indicated that twenty-two 48-inch (122-cm) diameter imperforate basket centrifuges--the largest size currently manufactured--would be required to treat the approximate 2 mgd (7500 cu m/day) of centrate flow from the existing centrifuge station. In the estimate, three standby units were provided. The cost of the centrifuges was supplied by the Sharples Centrifuge Company. The cost of a polymer system capable of providing a dosage of 4 lbs/ton (2.0 kg/metric ton) to the first stage centrate was estimated by Districts personnel. The provision was made for additional conveyor capacity for handling the second-stage generated cakes. A building was to be provided for housing both the horizontal scroll and basket centrifuges along with their respective cake conveyance systems. The building was assessed at $15.00/sq ft ($161.00/sq m). Controls for the basket centrifuge system would be housed in this building. The polymer station would be located outside.

The operating labor and power requirements were supplied by Sharples' personnel and were based on prior experience at other installations. Maintenance materials were estimated at 2 percent of equipment cost per year. Based on intended competitive bidding, polymer cost was estimated at $1.00 per pound ($2.20/kg). The operating cost of the first stage system was taken from the JWPCP cost records for the year 1971.

DEWATERING COSTS FOR COIL FILTRATION

A cost estimation for a coil filtration system using polymers as the conditioning agent is shown in Table 41. The parameters used in making the capital cost estimate were as follows:

(1) Polymer dosage....... 3000 lbs/day (1360 kg/day)

(2) Filter loading rate.. 12 lbs/hr/sq ft (58.6 kg/hr/sq m)

(3) Building area required............ 10,000 sq ft (930 sq m)

The filter loading rate was selected by Komline-Sanderson based on their analysis of the research data and falls well within the range of experimental data obtained. At

Table 41: COST ESTIMATE SUMMARY FOR VACUUM COIL FILTRATION WITH POLYMER CONDITIONING

CONDITIONS

1. Sludge conditioning:......... polymer dosage of 10 lb/ton (5.0 kg/metric ton)
2. Filtrate suspended solids:... 1500 mg/l
3. Cake solids:................. 18% solids by weight

CAPITAL COST

1.	Filters, pumps, etc. - installed	$ 620,000
2.	Polymer addition system - installed	90,000
3.	Building - 10,000 sq ft (930 sq m), installed	150,000
4.	Contractor - (10% of items 1 & 2)	70,000
5.	Contingencies	150,000
6.	Engineering - flat fee	100,000
	Total Capital Cost	$1,180,000

OPERATION & MAINTENANCE COST

1.	Labor	$ 44,000/yr
2.	Power	26,000/yr
3.	Water	50,000/yr
4.	Maintenance materials	10,000/yr
5.	Polymers	1,100,000/yr
	Total Operation & Maintenance Cost	$1,230,000/yr

design loading, four 11½-ft (3.5-m) diameter by 16-ft (4.9-m) wide filters would be required. Cost estimates for the filters was provided by Komline-Sanderson.

Labor and power requirements were provided by Komline-Sanderson. Water estimates were based on that required for polymer makeup, polymer dilution, and spray washing of the filter coils. Maintenance material was estimated at 2 percent of equipment costs. Polymer costs were estimated at $1.00 per pound ($2.20/kg).

DEWATERING COSTS FOR ROTARY-BELT VACUUM FILTRATION

An outlined cost estimate for a rotary-belt vacuum filtration system using lime conditioning is presented in Table 42. Capital costs were estimated on the basis of the following parameters:

(1)	Lime dosage..............	90 tons/day (82 metric tons/day) as $Ca(OH)_2$
(2)	Filter loading rate.......	1.5 lbs/hr/sq ft (7.3 kg/hr/sq m)
(3)	Building area required....	20,000 sq ft (1860 sq m)

Based on the 2-mgd (7500-cu m/day) design flow, thirty one filter units (including two standby units), each 12-ft (3.7-m) in diameter with a 20-ft (6.1-m) wide face, would be required. The costs for these filters was furnished by Envirotech Corporation; on the basis of experience at other installations, associated costs for labor, power, maintenance materials and water requirements were also provided. A lime cost of $23.25/ton ($25.60/metric ton) was used. Costs for a lime facility were obtained from Districts' records pertaining to the recent construction of an existing facility of identical capacity for the JWPCP chlorination station.

Presented in Table 43 is a cost estimate for a rotary-belt vacuum filtration system incorporating heat conditioning and intermediate thickening. The following parameters were used in making the capital cost estimates.

Table 42: COST ESTIMATE SUMMARY FOR ROTARY-BELT VACUUM FILTRATION WITH LIME CONDITIONING

CONDITIONS

1. Sludge conditioning:........ lime dosage of 600 lb/ton (300 kg/metric ton) as $Ca(OH)_2$

2. Filtrate suspended solids:... 200 mg/l

3. Cake solids:................. 35% solids by weight

CAPITAL COST

1. Filters - installed	$3,200,000
2. Chemical handling system - installed	1,000,000
3. Building - 20,000 sq ft (1860 sq m), installed	300,000
4. Conveyors - 400 ft (120 m)	50,000
5. Contractor - (10% items 1 & 2)	325,000
6. Contingencies	500,000
7. Engineering - flat fee	500,000
Total Capital Cost	$5,875,000

OPERATION & MAINTENANCE COST

1. Labor	$ 260,000/yr
2. Power	290,000/yr
3. Maintenance materials	20,000/yr
4. Chemicals	765,000/yr
5. Water	30,000/yr
Total Operation & Maintenance Cost	$1,365,000/yr

Table 43: COST ESTIMATE SUMMARY FOR ROTARY-BELT VACUUM FILTRATION WITH HEAT CONDITIONING AND INTERMEDIATE THICKENING

CONDITIONS

1. Sludge conditioning:......... Heat conditioning followed by gravity thickening
2. Filtrate suspended solids:... 3200 mg/1
3. Cake solids:................. 36% solids by weight

CAPITAL COST

1. Heat treatment - installed	$6,100,000
2. Thickeners - installed	170,000
3. Filters - installed	950,000
4. Building - 15,000 sq ft (1400 sq m), installed	225,000
5. Conveyor (200 ft.)	25,000
6. Contractor (10% of items 2, 3, & 5)	120,000
7. Contingencies	250,000
8. Engineering - flat fee	500,000
9. Biological treatment plant for effluent	2,500,000
Total Capital Cost	$10,840,000

OPERATION & MAINTENANCE COST

1. Labor	$ 155,000/yr
2. Power	120,000/yr
3. Fuel	350,000/yr
4. Water	25,000/yr
5. Maintenance material	40,000/yr
6. Biological treatment plant	250,000/yr
Total Operation & Maintenance Cost	$ 940,000/yr

(1)	Heat conditioning.........	40 min @ 350°F (175°C)
(2)	Thickener overflow rate....	225 gpd/sq ft (9.2 cu m/day/sq m)
(3)	Suspended solids reduction by heat conditioning......	20 percent
(4)	Filter loading rate........	4 lbs/hr/sq ft (19.5 kg/hr/sq m)
(5)	Building area required.....	15,000 sq ft (1400 sq m)

Based on the previous test work, cost estimates of the heat conditioning system, picket thickeners and vacuum filters along with the associated labor, power, maintenance materials and water requirements were furnished by Envirotech Corporation. Nine 150-gpm (9.5-l/sec) heat conditioning units, three 60-ft (18.3-m) diameter gravity picket thickeners, and seven 12-ft (3.7-m) diameter by 20-ft (6.1-m) wide vacuum filters (including one standby filter) would be needed for a full scale installation. A building would be furnished to house the vacuum filters and the controls for the thermal conditioning units, thickeners and filter units. The thickeners would be covered and located outside with the heat conditioning units. Vented reactor gases and trapped thickener gases would be discharged to an afterburner.

An estimate for biological treatment of the combined filtrate and thickener decantate was prepared by Districts' personnel. The estimate was based on the assumption that this high strength effluent waste would be amenable to biological treatment and that the sludge produced would settle in conventional final clarifiers. The biological facility would incorporate large turbine aerators and a lengthy detention time (more than 24 hours). Such a detention time would minimize sludge production such that the quantities requiring disposal would be insignificant. Power was determined to be the major operating cost of the biological treatment facility and was estimated to be in excess of $200,000 per year.

DEWATERING COSTS FOR PRESSURE FILTRATION

Capital and O & M costs for a pressure filtration system using lime and ferric chloride as conditioning agents are presented in Table 44. The parameters used in making the capital cost estimates were as follows:

(1) Chemical Dosage	
(a) Lime....................	75 tons/day (68 metric tons/day) as $Ca(OH)_2$
(b) Ferric Chloride........	18 tons/day (16.3 metric tons/day)
(2) Precoat (diatomaceous earth)........	4.5 lbs/100 sq ft (0.2 kg/sq m)
(3) Building area required......	15,000 sq ft (1400 sq m)

Based on test data, a total of four filter presses, each containing 140 chambers of 80-inch (200-cm) square plates, would be required. Filter press costs and the associated labor and power requirements were furnished by Beloit-Passavant. A cost estimate for the chemical handling system was made by Districts personnel. Water would be required for lime slaking. Maintenance and material costs were estimated at one percent of equipment costs. The entire system would be housed in a building costing $15.00/sq ft ($161.00/sq m). Chemical and precoat costs were assessed in accordance with the following:

(1) Lime........................	$23.25/ton ($25.60/metric ton)
(2) Ferric Chloride............	$120.00/ton ($132.40/metric ton)
(3) Diatomaceous earth.........	$68/ton ($68.00/metric ton)

DEWATERING COST SUMMARY

A summary of the cost estimates for the five dewatering systems considered is shown in Table 45. To arrive at a yearly cost and a cost per ton for each dewatering scheme, an amortization period had to be selected. It was

Table 44: COST ESTIMATE SUMMARY FOR PRESSURE FILTRATION WITH LIME AND FERRIC CHLORIDE CONDITIONING

CONDITIONS

1. Sludge conditioning:... Lime-500 lbs/ton (250 kg/metric ton) as $Ca(OH)_2$
$FeCl_3$ -120 lbs/ton (60 kg/metric ton)
Precoat (diatomaceous earth) - 4.5 lb/100 sq ft (0.2 kg/sq m)

2. Filtrate suspended solids:................ 100 mg/l

3. Cake solids:........... 40% solids by weight

CAPITAL COST

1.	Filters, pumps, conveyors, controls	$5,000,000
2.	Chemical handling, storage, feeding system - installed	1,300,000
3.	Building - 15,000 sq ft (1400 sq m), installed	225,000
4.	Installation (15% of item 1)	750,000
5.	Contingencies	500,000
6.	Engineering - flat fee	300,000
	Total Capital Cost	$8,075,000

OPERATION & MAINTENANCE COST

1.	Labor	$ 175,000/yr
2.	Power	45,000/yr
3.	Water	30,000/yr
4.	Maintenance material (1% of equipment)	50,000/yr
5.	Chemicals	1,700,000/yr
	Total Operation & Maintenance Cost	$2,000,000/yr

Table 45: SUMMARY OF COST ESTIMATE FOR FIVE POTENTIAL FULL-SCALE SLUDGE DEWATERING SCHEMES

PARAMETERS

1. Process Material:............ JWPCP primary digested sludge
2. Design Flow:................. 2 mgd (7500 cu m/day)
3. Effluent BOD:................ 1000 mg/l or less
4. Effluent Suspended Solids:... 1500 mg/l or less
5. Cake Solids:................. 18-40% solids by weight

CONDITIONING AND DEWATERING SYSTEM	CAPITAL COST -10^3\$-	O & M COST -10^3\$/yr	TOTAL COST* Yearly Basis -10^3\$/yr-	TOTAL COST* Tonnage Basis** -\$/ton-	PRESENT WORTH*** -10^3\$-
Two Stage Centrifugation (polymer conditioning in 2nd stage)	2,900	810	1,210	11.10	8,900
Vacuum Coil Filtration (polymer conditioning)	1,200	1,230	1,390	12.70	10,200
Rotary-Belt Vacuum Filtration (lime conditioning)	5,900	1,365	2,165	19.80	15,900
Rotary-Belt Vacuum Filtration (heat conditioning & intermediate thickening)	10,840	940	2,415	22.10	17,800
Pressure Filtration (lime & ferric chloride conditioning)	8,100	2,000	3,100	28.30	22,800

*Includes capital cost amortized at 6% for 10 years.
**Based on 300 dry tons (272 metric tons) per day.
***Based on 6% for 10 years.

Unit Conversions: ($/ton) x 1.103 = ($/metric ton)

decided that a 10-year period would be used for all estimates despite the fact that some of the dewatering equipment and the auxiliary capital items -- buildings, conveyors, etc. -- would probably have longer useful lives than that. The rationale used in making this decision was based on the uncertainty of future wastewater treatment methods at the JWPCP coupled with the possibility of future sludge disposal methods which would not necessitate dewatering. Hence, the sludge disposal system selected at this time would be considered an interim facility with a probable useful life of not more than 10 years. An interest rate of 6% was used in conjunction with the 10 year amortization period.

As can be seen from Table 45, there is a large variation in costs for the five systems considered. Capital cost varies from $1,200,000 for a vacuum coil filtration system to almost $11,000,000 for a heat conditioning-vacuum filtration scheme that would require a biological facility for further effluent treatment. Operating and maintenance costs also vary by a factor of almost three, with the two-stage centrifuge system exhibiting the lowest O&M cost of $810,000 per year.

The yearly costs of the dewatering schemes indicate that costs range from $11.10/ton ($12.20/metric ton) for a two-stage centrifuge system to $28.30/ton (31.20/metric ton) for pressure filters. The other system which utilizes polymer conditioning, i.e. coil vacuum filters, shows a relatively low cost of $12.70/ton ($14.00/metric ton). The two systems utilizing lime conditioning, i.e. belt vacuum filters and pressure filters, are more costly due to the high capital cost of the lime handling facility; also, the relatively low loading rate on the filters necessitates high capital expenses for dewatering equipment. The heat conditioning-vacuum filter scheme is relatively inexpensive as a dewatering system; however, the biological facility required for effluent treatment increases both the capital and operating cost of that scheme rather substantially.

ULTIMATE DISPOSAL COST -- TRUCK HAULING TO A LANDFILL

Presented herein are cost estimates for the full scale handling and disposal (truck hauling to a landfill) of dewatered sludge solids (cakes) generated by each of the previous five sludge dewatering schemes economically assessed. Some preliminary field studies were conducted at the Districts' Palos Verdes Landfill. Several truck loads of dewatered sludge were hauled to this facility and trial blended with various amounts of refuse. As a result it was determined that a dewatered sludge of 20% solids by weight or more could be effectively handled in the routine operation of a landfill.

Regarding the cost estimates, two District operated landfills -- the Mission Canyon Landfill and the Puente Hills Landfill -- were considered as possible disposal points. Both landfills are located about 30 miles (48.3 km) from the JWPCP by freeway and surface streets and have sufficient disposal capacity for the next 50 years. Despite the 6-mile (9.7-km) proximity of the Palos Verdes Landfill, the facility was not considered for ultimate disposal since its useful capacity will have been exhausted 3 years hence.

In making the cost estimate, some basic assumptions were made regarding the type of operation that would be followed. These, along with basic criteria used in deriving the estimates, are listed in the following.

(1) Dewatered sludge would be hauled on an 8-hr/day basis, seven days a week.

(2) Hauling would be done by truck and trailer rigs, each handling 23 tons/load (20.9 metric tons/load) and making 3 trips/day to the landfill site.

(3) Truck and trailer rigs would cost $42,000 each and have a 10,000-hr useful operating life which, on an 8-hr/day use basis, is equivalent to 3.4 years. Operation and maintenance (gas, tires, repairs, etc.) costs were assessed at $7.50/hr/rig and $8.00/hr/rig, respectively.

(4) Loading of the dewatered sludge onto hauling vehicles would be accomplished with 4-cu yd (3-cu m) bucket type skip loaders, each handling 120 tons/hr (109 metric tons/hr). Each loader would cost $67,000 and have a useful operating life of 10,000 hours (3.4 years on an 8-hr/day operating basis). Operation and maintenance costs were assessed at $10.50/hr/unit and $8.00/hr/unit, respectively.

(5) During periods of nonhauling (16 hr/day), dewatered sludge would be stored at the JWPCP. A total of 3-days storage capacity would be provided for in case of rain or operational difficulties at the landfill.

(6) Sludge storage and loading facilities at the JWPCP would be completely enclosed within a building. The building would house the sludge product in a triangular pile 25-ft (7.6-m) high by 75-ft (22.8-m) wide and of sufficient length for the required stored volume. The building would be 35-ft (10.7-m) high by 120-ft (36.6-m) wide and of necessary length to accomodate 3-day's storage. The building would be equipped with the necessary ventilation and air pollution equipment to prevent odors. Capital cost of the building was assessed at $15.00/sq ft ($161.00/sq m). Operating costs (labor to uncover and cover hauling rigs, tabulate payloads, wash trucks, etc. on an 8-hr/day, 7-day/wk basis) were figured on the basis of required manpower at a cost of $14,000/yr/man. Maintenance costs were assessed at 60¢/yr/sq ft ($6.50/yr/sq m) of building area.

(7) A second building would be necessary for the repair and maintenance of skip loaders and hauling rigs. The structure was sized on the basis of providing 100 sq ft (9.3 sq m) of floor area per vehicle for the total number of vehicles required in the disposal system. The capital cost of the building was assumed at $20/sq ft ($215/sq m).

(8) During periods of nonhauling, a paved parking area was assumed necessary for the truck and trailer rigs. Each rig would measure 8-ft (2.4-m) wide by 60-ft (18.3-m) long. To facilitate vehicle movement and parking, the area provided would be 2½ times the total area necessary to occupy all rigs. Pavement costs were assessed at $1.00/sq ft ($10.80/sq m).

(9) Maintenance and operation costs for both the vehicle maintenance building and the parking lot (power, lighting, washing, upkeep, etc.) were based on records of the Districts' past experiences.

Table 46 shows the individual components of capital and operating cost for hauling dewatered sludge to a landfill for each of the five dewatering systems investigated. The estimates were based on dewatering 300 dry tons/day (272 metric tons/day) of solids. In dewatering schemes where lime would be used as the conditioning agent, the quantity of solids appearing as lime in the dewatered cake was added to the 300 tons (272 metric tons) of sludge solids per day. In the case of heat conditioning, the quantity of solids to be hauled would be less than 300 tons/day (272 metric tons/day), reflecting the solubilization of solids during heat conditioning; for computational purposes, the generated cakes were assumed at 35% solids (instead of the 36% solids previously cited). In addition, the assumption was made that the 18% cakes generated by the coil-polymer filtration scheme could be rapidly air dried to 20% solids -- a value deemed necessary for hauling and landfill handling.

A summary of the dewatered sludge hauling costs is presented in Table 47. The capital cost of the truck rigs and skip loaders was amortized over a 3.4-year period (the approximate life of the vehicles based on 8-hr/day usage). To be consistent with the dewatering system amortization period, the buildings and parking area were amortized over a 10-year period. The estimated costs are seen to range from $10.90/ton ($12.00/metric ton) for a thermal-thickening-vacuum filtration scheme to $23.00/ton ($25.40/metric ton) for a coil vacuum filtration scheme. The low cost with the former was attributable to the reduced quantity and dry condition of the cakes necessitating hauling.

ULTIMATE DISPOSAL COST--PIPELINE TRANSPORT & LANDFILL DEWATERING

An alternative to truck hauling of dewatered sludge to a landfill disposal point is pipeline transport of the digested sludge to the landfill in its liquid form and dewatering thereat. This scheme affords the advantage of requiring fewer hauling rigs (some trucks would be required for transporting dewatered sludge within the landfill premises) which must be balanced against a high pipeline capital cost and the uncertainty of long distance sludge pumping.

Table 46: ITEMIZED COSTS FOR LANDFILL HAULING AND DISPOSAL OF DEWATERED SLUDGE FROM VARIOUS DEWATERING SYSTEMS

PARAMETERS

1. Material for disposal:... Dewatered primary digested sludge
2. Hauling mode:........... Truck and trailer rig
3. Hauling Period:......... 8 hrs/day, 7 days/wk
4. Landfill Distance:....... 30 miles (48 km) from JWPCP

DEWATERING SYSTEM / ITEM	TWO STAGE CENTRIFUGATION (polymer)	VACUUM COIL FILTRATION (polymer)	ROTARY-BELT VACUUM FILTRATION		PRESSURE FILTRATION (Lime & $FeCl_3$)
			(Lime)	Heat & Thickening)	
Cake Solids (%)	25	20	35	35	40
Quantity Hauled (tons/day)*	1,200	1,500	1,150	660	1,000
Capital Cost $(10^3\$)$					
1. Truck Rigs	760	960	755	460	670
2. Skip Loaders	135	200	135	135	135
3. Storage Bldg.	290	360	270	150	235
4. Maintenance Bldg.	40	55	40	30	40
5. Parking Area	25	25	25	15	30
TOTAL CAPITAL COST	1,250	1,600	1,225	790	1,100
O & M Cost $(10^3\$/yr)$					
1. Truck Rigs	765	990	765	450	680
2. Skip Loaders	110	160	110	110	110
3. Storage Bldg.	80	100	80	50	70
4. Maintenance Bldg.**	15	20	15	10	10
5. Landfill fee	660	820	630	360	550
TOTAL O & M COST	1,630	2,090	1,600	980	1,420

*Based on 300 dry tons/day of solids.

**Includes parking area.

Unit Conversions: (tons/day) x 0.907 = (metric tons/day)

Table 47: SUMMARY OF COSTS FOR LANDFILL HAULING AND DISPOSAL OF DEWATERED SLUDGE FROM VARIOUS DEWATERING SYSTEMS

PARAMETERS
1. Material for disposal:... Dewatered primary digested sludge
2. Hauling mode:............ Truck & trailer rig
3. Hauling Period:.......... 8 hrs/day, 7 days/wk
4. Landfill Distance:....... 30 miles (48 km) from JWPCP

DEWATERING SYSTEM		QUANTITY HAULED -tons/day-	CAPITAL COST $-10^3\$$-	O & M COST $-10^3\$$/yr-	TOTAL COST*		PRESENT WORTH $-10^3\$$-
					Yearly Basis $-10^3\$$/yr-	Tonnage Basis** -$/ton	
Two Stage Centrifugation (polymers to 2nd Stage)		1,200	1,250	1,630	1,970	18.00	13,900
Vacuum Coil Filtration (polymers)		1,500	1,600	2,090	2,520	23.00	17,900
Rotary-Belt Vacuum Filtration	(lime)	1,150	1,225	1,600	1,930	17.60	13,700
	(heat & thickening)	600	790	980	1,190	10.90	8,400
Pressure Filtration (lime & $FeCl_3$)		1,000	1,100	1,420	1,720	15.70	12,200

*Includes capital costs amortized on the following basis:
(a) Truck & trailer rigs and skip loaders @ 6% for 3.4 years.
(b) Buildings and parking area @ 6% for 10 years.

**Based on 300 dry tons/day of solids.

Unit Conversions: (tons/day) x 0.907 = (metric tons/day)
($/ton) x 1.103 = ($/metric ton)

In making the cost estimate for a pipeline to convey digested sludge to a landfill, the following assumptions were made:

(1) In accordance with a selected route along the Los Angeles River and Rio Hondo, the total pipeline distance would be 27.6 miles (44.4 km). On the basis of design flow and keeping the flowthrough velocity between 4-7 ft/sec (1.2-2.1 m/sec), a 14-inch (35.6-cm) diameter welded steel pipe would be used. The cost of the pipe, fittings, welding, excavation and backfilling, pipe placement and street repaving was estimated at $22/ft ($72/m).

(2) Sludge pumping to the landfill would be accomplished in a single hydraulic lift. The pump station would be located at the JWPCP and would consist of three positive displacement pumps (one would act as a standby unit) with 1100-hp (820-kw) ratings. The cost of each pump (including installation) would be about $55,000.

(3) A pump station would be located at the terminal landfill site for distribution of the incoming sludge slurry to the dewatering system. The cost of the station (including wet well, controls, instrumentation, etc.) was estimated from District records.

(4) Maintenance of the pipeline would include occasional pigging of the entire line -- a job estimated to require one full day to accomplish. A well equipped repair crew would be available to effect prompt repair of pipeline leaks. The costs associated with this was obtained from an analysis of data from other pipeline and high pressure slurry systems.

(5) The operation and maintenance costs for the pump stations at both the JWPCP and the terminal landfill site were determined from the Districts' records of its own operating experiences.

(6) The effluent from the landfill dewatering station would be disposed of in the Districts' sewerage system.

(7) The dewatered sludge would be stored at the landfill for a 15-hour period with landfilling to take place only during the regular landfill operating periods. The sludge storage and handling facility would be identical to that discussed in the previous section for the truck hauling scheme.

(8) The costs for disposal of the dewatered sludge cake were derived using the same assumptions for truck costs in the previous sludge hauling section.

Presented in Table 48 is an itemized cost breakdown for a pipeline-landfill disposal system for each of the five dewatering schemes previously selected. As noted, the cost of the pipeline portion of the system would be identical for each dewatering scheme since, in all cases, the same volumetric quantity of sludge slurry would require transportation to the landfill site. Included in the operating cost is a sewer connection surcharge for discharge of the effluent from the dewatering system alternatives. This fee was calculated from a formula contained in the Districts' Industrial Waste Ordinance.

A summary of the pipeline transportation and landfill disposal costs for the five dewatering alternatives is presented in Table 49. In amortizing the capital cost of the pipeline, a pipeline life of 20 years was assumed. Though inconsistent with the 10-year amortization period used for the dewatering system alternatives, justification for the 20-year period was based on the assumption that the pipeline would play a vital role in an ultimate disposal scheme for the future. On a dry tonnage basis, the estimated pipeline transportation and landfill disposal costs ranged from $15.25/ton ($16.80/metric ton) for the thermal-thickening-filtration scheme to $22.10/ton ($24.40/metric ton) for a coil vacuum filtration scheme. As with the truck hauling disposal costs (discussed in the previous section), the low cost associated with the thermal-thickening-filtration scheme was attributed to the lesser quantity of solids requiring disposal (a consequence of thermal destruction and solubilization). However, because the pipeline itself would be a substantial portion of the total cost and because its cost would be independent of the method of sludge dewatering, the difference between the lowest and highest pipeline-

Table 48: ITEMIZED PIPELINE-DISPOSAL COSTS FOR VARIOUS DEWATERING SYSTEMS

PARAMETERS
1. Material pipelined:...... JWPCP primary digested sludge
2. Pipeline Distance:....... 27.6 miles (44.4 km)
3. Dewatering & Disposal:... at landfill

DEWATERING SYSTEM / ITEM	TWO STAGE CENTRI-FUGATION (polymer)	VACUUM COIL FILTRATION (polymer)	ROTARY-BELT VACUUM FILTRATION		PRESSURE FILTRATION (Lime & $FeCl_3$)
			(Lime)	Heat & Thickening)	
Capital Cost (10^3\$)					
1. Pipeline	3,220	3,220	3,220	3,220	3,220
2. Pump station @JWPCP	330	330	330	330	330
3. Pump station @landfill	110	110	110	110	110
4. Effluent sewer connection	50	50	50	50	50
5. Truck & skip loaders	300	410	300	260	300
6. Storage Bldg.	540	675	520	300	450
7. Maintenance bldg*	60	80	60	40	55
TOTAL CAPITAL COST	4,610	4,875	4,590	4,310	4,515
O & M Cost (10^3\$/yr)					
1. Pipeline	10	10	10	10	10
2. Pump station @JWPCP	180	180	180	180	180
3. Pump station @landfill	30	30	30	30	30
4. Sewer connection surcharge	100	110	80	250	60
5. Trucks & skip loaders	260	360	260	215	260
6. Storage bldg.	100	125	100	60	80
7. Maintenance bldg*	10	10	10	10	10
8. Landfill fee	660	820	630	360	550
TOTAL O & M Cost	1,350	1,645	1,300	1,115	1,180

*Includes parking area.

NOTE: Refer to Table 46 for tonnages requiring disposal

Table 49: SUMMARY OF PIPELINE-DISPOSAL COSTS FOR VARIOUS DEWATERING SYSTEMS

PARAMETERS
1. Material Pipelined:...... JWPCP primary digested sludge
2. Pipeline Distance:....... 27.6 miles (44.4 km)
3. Dewatering & Disposal:... at landfill

DEWATERING SYSTEM	CAPITAL COST -10^3\$-	O & M COST -10^3\$/yr-	TOTAL COST*		PRESENT WORTH*** -10^3\$-
			Yearly Basis -10^3\$/yr-	Tonnage Basis** -\$/ton-	
Two Stage Centrifugation (polymers to 2nd Stage)	4,610	1,350	2,020	18.50	14,600
Vacuum Coil Filtration (polymers)	4,875	1,645	2,420	22.10	17,000
Rotary-Belt Vacuum Filtration (Lime)	4,590	1,300	1,940	17.75	14,200
Rotary-Belt Vacuum Filtration (Heat & Thickening)	4,310	1,115	1,670	15.25	12,500
Pressure Filtration (lime & $FeCl_3$)	4,515	1,180	1,810	16.50	13,200

*Includes capital cost amortized on the following basis
- (a) Pipeline @ 6% for 20 years
- (b) Trucks and skip loaders @ 6% for 3.4 years
- (c) Buildings and parking area @ 6% for 10 years.

**Based on 300 dry tons/day (272 metric tons/day) of solids.

***Based on 6% for 10 years.

Unit Conversions: (\$/ton) x 1.103 = (\$/metric ton) transportation, landfill-disposal cost is seen to be less than that difference encountered for truck transportation of dewatered sludge from the JWPCP.

ULTIMATE DISPOSAL COST -- INCINERATION WITH LANDFILL DISPOSAL OF ASH RESIDUE

A third disposal alternative was that of dewatered sludge incineration at the JWPCP with truck hauling of the ash residue to a landfill. A pilot incinerator had been under evaluation at the JWPCP sludge dewatering research site for several months. All of the testing done on the unit was conducted on a short-term batch basis to assess the burning capabilities of the various cakes generated from the piloted dewatering systems investigated. Although the results of this work are not contained herein, the derived data enabled optimum loading rates to be determined as a function of cake moisture and volatile solids content. Because the incinerator unit was not operated in a long-term, steady-state manner, air pollution measurements were not attempted.

Cost estimates for incinerators to burn the various dewatered sludge cakes from the five alternative dewatering schemes were furnished by Envirotech Corporation. The estimates included the necessary air pollution control equipment to meet or exceed the existing APCD standards. The incinerators were sized from heat value data and loading rates acquired from the Districts' research work. The above estimates are presented in Table 50 along with other itemized costs related to truck hauling of the incinerated ash residue to a landfill. The basis for deriving the ash handling and disposal costs were identical to those used for direct handling and hauling of dewatered sludge cakes except that incinerator ash would be stored on the JWPCP's acreage for 15 hours per day, with the full day's production being hauled to the landfill during the 8-hour daytime period. Operation and maintenance costs for the incineration system were provided by Envirotech Corporation.

A summary of the incineration and ash hauling estimates for each of the five potential dewatering alternatives is presented in Table 51. The thermal-thickening-filtration system provided the lowest cost of $8.30/ton

Table 50: ITEMIZED COSTS FOR DEWATERED SLUDGE INCINERATION WITH ASH HAULING TO A LANDFILL

PARAMETERS

1. Material for disposal:... Dewatered primary digested sludge
2. Ash hauling mode:........ Truck and trailer rig
3. Hauling period:.......... 8 hrs/day, 7 days/wk
4. Landfill Distance:....... 30 miles (48 km) from JWPCP

DEWATERING SYSTEM / ITEM	TWO STATE CENTRIFUGATION (polymer)	VACUUM COIL FILTRATION (polymer)	ROTARY-BELT VACUUM FILTRATION		PRESSURE FILTRATION (Lime & $FeCl_3$)
			(Lime)	(Heat & Thickening)	
Incinerators required	2	3	2	2	2
Ash to be hauled* (tons/day)	130	155	210	110	210
Capital Cost ($10^3$$)					
1. Incinerators	2,700	3,500	2,600	1,750	2,500
2. Site preparation	100	100	100	100	100
3. Trucks & skip loaders	260	300	300	260	300
4. Maintenance bldg.**	25	25	25	25	25
TOTAL CAPITAL COST	3,085	3,925	3,025	2,135	2,925
O & M Cost ($10^3$$/yr)					
1. Fuel	750	1,620	870	225	665
2. Power	30	35	30	15	25
3. Labor	20	20	20	20	20
4. Maintenance materials	10	10	10	10	10
5. Ash handling system***	305	385	425	285	425
TOTAL O & M COST	1,115	2,070	1,355	555	1,145

*Based on 300 dry tons/day less 99.5 percent destruction of volatile component.

**Includes parking area.

***Includes truck & trailer rigs,skip loaders, maintenance building and parking area.

Unit Conversions: (tons/day) x 0.907 = (metric tons/day)

Table 51: SUMMARY OF COSTS FOR DEWATERED SLUDGE INCINERATION WITH ASH HAULING TO A LANDFILL

PARAMETERS
1. Material for disposal:... Dewatered primary digested sludge
2. Ash hauling mode:........ Truck & trailer rig
3. Hauling period:.......... 8 hrs/day, 7 days/wk
4. Landfill Distance:....... 30 miles (48 km) from JWPCP

DEWATERING SYSTEM	QUANTITY OF ASH HAULED -tons/day-	CAPITAL COST -10^3\$-	O & M COST -10^3\$/yr-	TOTAL COST*		PRESENT WORTH*** -10^3\$-
				Yearly Basis -10^3\$/yr-	Tonnage Basis** -\$/ton-	
Two Stage Centrifugation (polymers to 2nd Stage)	130	3,085	1,115	1,600	14.60	11,300
Vacuum Coil Filtration (polymers)	155	3,925	2,070	2,690	24.50	19,200
Rotary-Belt Vacuum Filtration (Lime)	210	3,025	1,355	1,850	16.90	13,000
Rotary-Belt Vacuum Filtration (Heat & Thickening)	110	2,135	555	910	8.30	6,300
Pressure Filtration (lime & $FeCl_3$)	210	2,925	1,150	1,620	14.80	11,400

*Includes capital costs amortized on the following basis:
(a) Incinerators, building and parking area @ 6% for 10 years
(b) Truck & trailer rigs and skip loaders @ 6% for 3.4 years.

**Based on 300 dry tons/day of solid handled.

***Based on 10 years @ 6%.

Unit Conversions: (tons/day) x 0.907 = (metric tons/day)
($/ton) x 1.103 = ($/metric ton)

($9.20/metric ton). This was attributed to the high heat value and low moisture content of the dewatered sludge and to the low tonnage of solids requiring processing. The incinerator estimates are based on an operation which would result in exit gas temperatures of 1600°F (870°C). Though this value greatly exceeds that needed for proper incineration, a requirement for such was anticipated in regards to a forthcoming EPA Task Force report. If the future indicated that this would not be required, then a substantial savings in fuel utilization would result.

COST SUMMARY OF SLUDGE PROCESSING SYSTEMS

Presented in Table 52 are summarized cost estimates for digested sludge dewatering at the JWPCP with subsequent hauling of dewatered sludge to a landfill for disposal. These costs were derived by combining the disposal costs in Table 47 with those in Table 45 for each of the five potential full-scale dewatering schemes under consideration. The combined costs indicated that a two-stage centrifugation system would be the most economical dewatering system when hauling was the disposal method. The total sludge handling cost was estimated at $29.10/ton ($32.10/metric ton), with about 40 percent attributable to dewatering and 60 percent attributable to disposal of the dewatered sludge. It is to be recalled that this estimate excluded the cost incurred for the existing horizontal scroll centrifuge station. Replacement costs for this facility would approximate $1,000,000; this would increase the above estimate by an additional $2.00/ton ($2.20/metric ton).

Contained in Table 53 are summarized cost estimates for pipeline transportation of the JWPCP primary digested sludge to a landfill with subsequent dewatering and disposal thereat. These costs were obtained by combining the estimates in Table 49 with those in Table 45 (with some modifications) for each of the dewatering schemes considered. Dewatering cost modifications were required in accordance with the following:

(1) With dewatering at the landfill, the existing horizontal scroll centrifugation system at the JWPCP would not be utilizable unless it was moved to the landfill site and reinstalled. Hence, the estimates for the two-stage centrifugation scheme was increased to include the construction and installation costs for such a relocation.

Table 52: TOTAL SLUDGE HANDLING COST SUMMARY--Dewatering at JWPCP with Truck Hauling for Landfill Disposal

PARAMETERS

1. Dewatered Material:... JWPCP primary digested sludge
2. Hauling Period:....... 8 hrs/day, 7 days/wk
3. Landfill Distance:.... 30 miles (48 km) from JWPCP

DEWATERING SYSTEM	CAPITAL COST -10^3\$-	O & M COST -10^3\$/yr-	TOTAL COST* Yearly Basis -10^3\$/yr-	TOTAL COST* Tonnage Basis** -\$/ton-	PRESENT WORTH*** -10^3\$-
Two Stage Centrifugation† (polymers to 2nd Stage)	4,150	2,440	3,180	29.10	22,800
Vacuum Coil Filtration (polymers)	2,800	3,320	3,910	35.70	28,100
Rotary-Belt Vacuum Filtration (Lime)	7,125	2,965	4,095	37.40	29,600
Rotary-Belt Vacuum Filtration (Heat & Thickening)	11,630	1,920	3,605	33.00	26,200
Pressure Filtration (lime & $FeCl_3$)	9,200	3,420	4,820	44.00	35,000

*Includes capital costs amortized on the following basis:
(a) Truck & trailer rigs and skip loaders @ 6% for 3.4 years
(b) Dewatering station, buildings and parking area @ 6% for 10 years.

**Based on 300 dry tons/day (272 metric tons/day) of solids handled.

***Based on 6% for 10 years.

†Does not include $1,000,000 capital value of existing first stage centrifuges equivalent to an additional $2.00/ton total cost.

Unit Conversions: ($/ton) x 1.103 = ($/metric ton)

Table 53: TOTAL SLUDGE HANDLING COST SUMMARY--Pipeline Transportation and Landfill Dewatering and Disposal

PARAMETERS
1. Transported and Dewatered Material:... JWPCP primary digested sludge
2. Pipeline Distance:..................... 27.6 miles (44.4 km)

DEWATERING SYSTEM		CAPITAL COST $-10^3\$$-	O & M COST $-10^3\$/yr$-	TOTAL COST*		PRESENT WORTH*** $-10^3\$$-
				Yearly Basis $-10^3\$/yr$-	Tonnage Basis** -$/ton-	
Two Stage Centrifugation† (polymers to 2nd Stage)		8,210	2,160	3,320	30.40	24,100
Vacuum Coil Filtration (polymers)		6,075	2,875	3,810	34.80	27,200
Rotary-Belt Vacuum Filtration	(Lime)	10,490	2,665	4,125	37.75	30,100
	(Heat & Thickening)	12,610	1,805	3,235	29.50	25,900
Pressure Filtration (lime & $FeCl_3$)		12,615	3,180	4,910	44.80	36,000

*Includes capital cost amortized on the following basis:
(a) Pipeline @ 6% for 20 years
(b) Trucks and skip loaders @ 6¢ for 3.4 years
(c) Dewatering station, buildings and parking area @ 6% for 10 years.

**Based on 300 dry tons/day (272 metric tons/day) of solids handled.

***Based on 6% for 10 years.

†Does not include $1,000,000 capital value of existing first stage centrifuge equivalent to an additional $2.00/ton total cost.

Unit Conversions: ($/ton) x 1.103 = ($/metric ton)

(2) Regarding the thermal-thickening-filtration scheme, the associated pipeline cost was derived to reflect the industrial waste surcharge pertinent to the high BOD and suspended solids in the effluent from that dewatering system. Hence, the estimate for the dewatering scheme was adjusted to exclude the capital and O & M costs for biological treatment.

The combined costs indicated that the most economical system utilizing pipeline transporation was that incorporating the thermal-thickening-filtration scheme at the landfill. In this regard, the total sludge handling cost was estimated at $29.50/ton ($32.50/metric ton). Of this total, about 48 percent was attributable to dewatering, with the remaining 52 percent associated with pipeline transportation and landfill disposal.

Presented in Table 54 are summarized cost estimates for digested sludge dewatering at the JWPCP with subsequent disposal of the dewatered sludge by incineration and ash hauling to a landfill. These costs were acquired by combining the disposal costs in Table 51 with those in Table 45 (with one modification) for each of the dewatering alternatives. The thermal-thickening-filtration estimates were modified to reflect a savings in heat conditioning fuel costs resulting from the use of recovered heat from the incineration process. As is noted, the most economical system employing incineration and ash hauling was that incorporating sludge dewatering by two-stage centrifugation. The total sludge handling cost for this sytem was estimated at $25.70/ton ($28.30/metric ton). Sludge dewatering comprised about 43 percent of this total, with the remaining 57 percent attributable to disposal.

A summary of the total costs of the five alternative dewatering schemes for each of the three disposal alternatives is presented in Table 55. As is noted, the estimates associated with each method of disposal are ranked in order of increasing cost. Of the fifteen alternatives, two-stage centrifugation with incineration and ash hauling provided the most economical means of sludge handling and disposal. Accordingly, the total cost for such a system would be $25.70/ton ($28.30/metric ton) or about $2.8 million/yr based on handling 300 dry tons/day (272 metric tons/day) of solids; this is about 12 percent

Table 54: TOTAL SLUDGE HANDLING COST SUMMARY--Dewatering and Subsequent Incineration at JWPCP with Truck Hauling of Ash to Landfill

PARAMETERS

1. Dewatered Material:... JWPCP primary digested sludge
2. Hauling Period:....... 8 hrs/day, 7 days/wk
3. Landfill Distance:.... 30 miles (48 km) from JWPCP

DEWATERING SYSTEM		CAPITAL COST -10^3\$-	O & M COST -10^3\$/yr-	TOTAL COST* Yearly Basis -10^3\$/yr-	TOTAL COST* Tonnage Basis** -\$/ton	PRESENT WORTH*** -10^3\$-
Two Stage Centrifugation† (polymers to 2nd Stage)		5,985	1,925	2,810	25.70	20,200
Vacuum Coil Filtration (polymers)		5,125	3,300	4,080	37.20	29,400
Rotary-Belt Vacuum Filtration	(Lime)	8,925	2,720	4,015	36.70	28,900
	(Heat & Thickening)	12,975	1,320	3,150	28.75	22,800
Pressure Filtration (lime & $FeCl_3$)		11,025	3,150	4,720	43.10	34,200

*Includes capital costs amortized on the following basis:
(a) Dewatering station, incinerators, building and parking area @ 6% for 10 years
(b) Truck & trailer rigs and skip loaders @ 6% for 3.4 years.

**Based on 300 dry tons/day (272 metric tons/day) of solids handled.

***Based on 6% for 10 years.

†Does not include \$1,000,000 capital value of existing first stage centrifuge equivalent to an additional \$2.00/ton total cost.

Unit Conversions: (\$/ton) x 1.103 = (\$/metric ton)

Table 55: SUMMARY COST COMPARISON OF ALTERNATIVE SLUDGE HANDLING SYSTEMS

DISPOSAL ALTERNATIVE	DEWATERING SYSTEM ALTERNATIVE	TOTAL COST*	
		Yearly Basis -10^3\$/yr-	Tonnage Basis** -\$/ton-
Truck Hauling to a Landfill	1. Two Stage Centrifugation (polymers to 2nd Stage)†	3,180	29.10
	2. Rotary-Belt Vacuum Filtration (heat & thickening)	3,605	33.00
	3. Vacuum Coil Filtration (polymers)	3,910	35.70
	4. Rotary-Belt Vacuum Filtration (lime)	4,095	37.40
	5. Pressure Filtration (lime & $FeCl_3$)	4,820	44.00
Pipeline Transportation with Landfill Dewatering & Disposal	1. Rotary-Belt Vacuum Filtration (heat & thickening)	3,235	29.50
	2. Two Stage Centrifugation (polymers to 2nd stage)†	3,320	30.40
	3. Vacuum Coil Filtration (polymers)	3,810	34.80
	4. Rotary-Belt Vacuum Filtration (lime)	4,125	37.75
	5. Pressure Filtration (lime & $FeCl_3$)	4,910	44.80
Incineration with Ash Hauling to a Landfill	1. Two Stage Centrifugation (polymers to 2nd stage)†	2,810	25.70
	2. Rotary-Belt Vacuum Filtration (heat & thickening)	3,150	28.75
	3. Rotary-Belt Vacuum Filtration (lime)	4,015	36.70
	4. Vacuum Coil Filtration (polymers)	4,080	37.20
	5. Pressure Filtration (lime & $FeCl_3$)	4,720	43.10

*Cost pertain to the complete handling of JWPCP primary digested sludge.
**Based on 300 dry tons/day (272 metric tons/day) of solids handled.
†Does not include $1,000,000 capital value of existing first stage centrifuge equivalent to an additional $2.00/ton total cost.

Unit Conversions: ($/ton) x 1.103 = ($/metric ton)

lower than the lowest cost estimated for the other two disposal alternatives. The thermal-thickening-filtration scheme with incineration and ash hauling was the next lowest cost alternative. Ranking third was two stage centrifugation in combination with truck hauling to a landfill. Falling close behind this was the system incorporating pipeline transportation with landfill dewatering by the thermal-thickening-filtration scheme. All other schemes were estimated to be in excess of $30.00/ton ($33.00/metric ton).

Although incineration yielded the lowest total system cost, it was felt that the social and technical problems associated with the air pollution dilemma in Los Angeles would place the Districts in a questionable position should such a system be constructed. Also, the APCD might impose more stringent standards if incineration were proposed; this would necessitate additional capital expenditures for more air pollution control equipment which could conceivably render the system uneconomical. Further, the possibility existed that the atmospheric discharge of certain substances (pesticides, heavy metals, etc.) would not be sufficiently controllable by any means. In view of these unknowns, the low cost incinceration system was eliminated for further consideration.

In addition to affording the next most economical system, the two-stage centrifugation-truck hauling scheme afforded the advantage of a relatively low capital cost -- a factor which was desirable in a system having a short life. Also, the reliability and flexibility of the system had been demonstrated quite clearly. On the other hand, pipeline transportation of digested sludge to a landfill disposal point had the advantages of eliminating the placement of large trucks on an already congested freeway system, eliminating the accompanying air pollutants discharged by the trucks, and combining the dewatering and disposal systems in the same physical location; in addition, the effluent from the dewatering station would be discharged to the sewer rather than directly to the ocean, thus relaxing the strict effluent quality restrictions on the dewatering system. Corresponding disadvantages were the high capital cost of the pipeline itself, the unknowns involved in pumping digested sludge over long distances, and the effects of such on sludge dewaterability.

COST SUMMARY FOR REMOTE DISPOSAL

A future alternative for ultimate disposal of digested sludge from the JWPCP is that of remote disposal. Multiple possibilities exist for sludge disposal to a remote area. Two such possibilities are considered herein, namely rail or pipeline transport to the upper desert region with disposal by either lagooning or soil reclamation. Because many basic assumptions were necessary to derive the comparative costs, it is to be realized that the estimates presented herein do not possess the accuracy of those pertaining to the dewatering-diposal alternatives presented in prior sections. However, they do enable an "order of magnitude" comparison to be made.

In making the cost estimate for a pipeline to convey digested sludge from the JWPCP to a remote area, the following criteria and assumptions were used:

(1) Without selecting a particular location for the pipeline terminus, it was estimated that a 14-inch (35.6-cm) diameter, 100-mile (161-km) long, welded steel pipe would be required. A maximum static head of 3500 ft (1067 m) was assumed.

(2) Pipeline pumping would be accomplished with three pump stations, each located at intervals along the route.

(3) A control system for the entire route plus storage tanks at the JWPCP and the terminus would be provided.

(4) Capital and O & M costs would be derived in a manner similar to those previously acquired for the pipeline-landfill transportation scheme.

The criteria used for deriving the cost estimate for rail transportation to a remote area were as follows:

(1) Digested sludge would be thickened (using polymers) to a solids concentration of 6% (60,000 mg/l) at the JWPCP and then hauled daily to the remote disposal point in 20,000-gal. (75.7-cu m) railroad tank cars.

(2) Assuming a roundtrip time of 24 hours, 100 tank cars would be required (including 16 cars for emergency and standby purposes), each having an approximate purchase price of $25,000. Operation and maintenance costs were assessed at 2¢/car/mile (1.24¢/car/km).

(3) In consultation with the Southern Pacific Railroad Company, freight charges of $200/car/round trip would be levied less $18/car/100 miles ($11.20/car/100 km) when fully loaded; on a net basis, this would amount to about $5.9 million/yr.

(4) Sludge loading into the tank cars would be accomplished with a semi-automated system. At the terminus, a trestle arrangement would enable transported sludge to be gravity drained into a lined sump from which it would be pumped into enclosed storage tanks to await disposal.

(5) Since a main railroad line presently passes through the JWPCP acreage, only a spur would be required to convey the tank cars in and out of the premises. At the terminus, however, five miles of trackage were assumed necessary to get the loaded cars from a main line to some remote disposal site.

The requirements and cost estimates for remote disposal by lagooning were based on the following criteria:

(1) Sealed lagoons having a 6-ft (1.8-m) initial depth would be provided such that the permeability would be 0.002 ft (0.061 cm) of water per year (a WQCB requirement). Assuming an evaporation rate of 80 in/yr (203 cm/yr) and a dried sludge density of 30 lb/cu ft

(480 kg/cu m), the useful life of each lagoon would be 10 years. Hence, 2000 acres (810 ha) would be required to provide for a 30-year capacity.

(2) For estimate purposes, the total 2000 acres (810 ha) would be purchased but only 540 acres (220 ha) of lagoons would be constructed. Land costs were assessed at $2500/acre ($1012/ha) and the cost for constructing the 540 acres (220 ha) of lagoon capacity was estimated at $7,000,000. Distribution piping, loading and spreading equipment, and the necessary facilities for labor forces and equipment was estimated at $1,000,000.

(3) The operation and maintenance costs would include property taxes of 10% of the assessed value. No allowances would be made for the leasing of the 1460 acres (590 ha) not being used initially for lagoons.

Soil reclamation costs were derived on the basis of the following assumptions and criteria:

(1) A 10,000-acre (4050-ha) land capacity would be purchased at $2500/acre ($1012/ha). The assumption was made that adjacent acreage would be available and, therefore, purchased as was needed to maintain the reclamation operation. Distribution piping and the equipment necessary for sludge spreading and tilling with the soil was assessed at $1,000,000.

(2) The operation and maintenance costs would include property taxes of 10% of the assessed value. It was assumed that a 10,000-acre (4050-ha) inventory would always be maintained. No credit was assumed for the sale or leasing of reclaimed acreage.

The individual capital and operation & maintenance costs for each of the remote area transportation and disposal alternatives are presented in Table 56. In terms of a total system, these individual costs would combine into the system costs shown in Table 57. The pipeline transport-lagooning scheme would bear some consideration because of its low operating cost ($800,000/yr). If the capital cost is amortized at 6% over a 30-year period, the total yearly cost would approximate $3,000,000,

TABLE 56: REMOTE AREA TRANSPORTATION AND ULTIMATE DISPOSAL COSTS

PARAMETERS

1. Material for Disposal:... JWPCP primary digested sludge
2. Remote Area Location:.... approximately 100 miles (161 km) from JWPCP

FUNCTION	MODE	CAPITAL COST -10^3\$-	O & M COST -10^3\$/yr-
Transportation	1. Pipeline	17,000	600
	2. Rail	5,000	7,000
Disposal	1. Lagooning	13,000	200
	2. Soil Reclamation	26,000	900

TABLE 57: COMPARISON OF REMOTE DISPOSAL SYSTEM COSTS

PARAMETERS

1. Material for Disposal:... JWPCP primary digested sludge
2. Remote Area Location:.... approximately 100 miles (161 km) from JWPCP

REMOTE DISPOSAL SYSTEM	CAPITAL COST -10^3\$-	O & M COST -10^3\$/yr-
1. Pipeline transport & lagooning	30,000	800
2. Pipeline transport & soil reclamation	43,000	1,500
3. Rail transport & lagooning	18,000	7,200
4. Rail transport & soil reclamation	31,000	7,900

or $27.50/ton ($30.30/metric ton) based on 300 dry tons/day (272 metric tons/day) of solids handled. This estimate is slightly below the $29.10/ton ($32.10/metric ton) estimated for the two-stage centrifugation system with truck hauling to a landfill. The pipeline transport-soil reclamation scheme might also merit consideration since the operation and maintenance costs conservatively excluded any savings which would be attributable to the yearly sale of reclaimed land. The high operation and maintenance costs for the trail transport schemes are attributed mostly to the levied freight charges. Since these charges were relatively firm and fixed, economic consideration for such an operation would be unjustifiable.

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